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Productivity Growth and Convergence in Crop, Ruminant and Non-Ruminant Production: Measurement and Forecasts

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Abstract

There is considerable interest in projections of future productivity growth in agriculture. Whether one is interested in the outlook for global commodity markets, future patterns of international trade, or the interactions between land use, deforestation and ecological diversity, the rate of productivity growth in agriculture is an essential input. Yet solid projections for this variable have proven elusive – particularly on a global basis. This is due, in no small part, to the difficulty in measuring historical productivity growth. The purpose of this paper is to report the latest time series evidence on total factor productivity growth for crops, ruminants and non-ruminant livestock, on a global basis. We then follow with tests for convergence amongst regions, providing forecasts for farm productivity growth to the year 2040. The results suggest that most regions in the sample are likely to experience larger productivity gains in livestock than in crops. Within livestock, the non-ruminant sector is expected to continue to be more dynamic than the ruminant sector. Given the rapid rates of productivity growth observed recently, non-ruminant and crop productivity in developing countries may be converging to the productivity levels of developed countries. For ruminants, the results show that productivity levels may be diverging between developed and developing countries.

JEL Classification: D24, O13, O47, Q10

Key words: Malmquist index, productivity, convergence, projections, crops, livestock

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1. Introduction

There is considerable demand for projections of future productivity growth in agriculture. Whether one is interested in the outlook for global commodity markets (OECD-FAO, 2005), future patterns of international trade (Anderson et al., 1997), or the interactions between land use, deforestation and ecological diversity (Ianchovichina et al., 2001), the rate of productivity growth in agriculture is an essential input. Yet solid projections for this variable have proven elusive – particularly on a global basis. This is due, in no small part, to the difficulty in measuring historical productivity growth. The purpose of this paper is to present the latest time series evidence on total factor productivity growth for crops, ruminants and non-ruminant livestock, on a global basis. We then follow with tests for convergence amongst regions, and provide forecasts for farm productivity growth to the year 2040.

Productivity measurement in agriculture has captured the interest of economists for a long time. Coelli and Rao (2005) present a review of multi-country agriculture productivity studies, reporting a total of 17 studies in the decade between 1993 and 2003. The majority of these studies indicate technological regression for developing countries and technological progress for developed countries. Coelli and Rao however find that there has been technological progress for all regions in the sample.

Most of the studies on productivity growth in agriculture have focused on sector-wide productivity measurement, with less attention to the estimation of sub-sector productivity. This omission is not because of a lack of interest, but for reasons of data availability on input allocation to individual activities. Because of this lack of information, sub-sector productivity has usually been assessed using partial factor productivity (PFP) measures such as "output per head of livestock" and "output per hectare of land". However, PFP is an imperfect measure of productivity. For example, if increased output per head of livestock is obtained by more intensive feeding of animals, then total factor productivity growth may be unchanged, despite the apparent rise in PFP. In general, the issue of factor substitution can lead PFP measures to provide a misleading picture of performance (Capalbo and Antle, 1988).

A more accurate measure of productivity growth must account for all relevant inputs, hence the name: *Total* Factor Productivity (TFP). However, TFP measurement requires a complete allocation of inputs to specific agricultural subsectors. For example, how much labor time was allocated to crop production and how much to livestock production on any given farm, or in a given country? Given the importance of this problem, the literature is extensive on this topic. To overcome this problem, Nin et al. (2003) propose a directional Malmquist index that finesses unobserved input allocations across agricultural sectors. They use this methodology to generate multi-factor productivity for crops and livestock. This technique will form the basis for the historical analysis presented in this paper.

However, we first update and extend the work of Nin et al. (2003), to account for the wide differences in productivity growth among different species of livestock (Delgado et al., 1999; Rae and Hertel, 2000; Nin et al., 2004). Delgado et al. show that between 1982 and 1994, output per head in beef grew at 0.5, milk grew at 0.2, pork grew at 0.6, and poultry grew at 0.7 percent per year. Rae and Hertel show that in Asia the rate of growth in this partial factor productivity measure for non-ruminants (pigs and poultry) was sharply higher than the rate of productivity growth in ruminants (cattle, sheep and goats). With these kinds of differences in partial factor productivity, it is likely that there are also large divergences in TFP. Therefore, in this paper, we extend the work of Nin et al. (2003), by disaggregating livestock productivity measures into ruminant and non-ruminant measures using FAO data between 1961 and 2001.

A key part of this historical analysis is the decomposition of productivity growth into two components: technical change, or movement in the technology frontier for a given sub-sector, and "catching up", which represents improved technology bringing the country in question closer to the global frontier (Färe et al., 1994). We believe that forecasts of future productivity growth must distinguish between these two elements of technical progress, and this is reflected in our approach to forecasting future technology.

Having produced this historical time series for total factor productivity by agricultural sub-sector, we then test for productivity convergence across regions, using time series techniques. These time series relationships also form the basis for our forecasts of productivity growth over the period 2001-2040.

The results suggest that most regions in the sample are likely to experience larger productivity gains in livestock than in crops. Within livestock, the non-ruminant sector TFP growth is expected to continue to be larger than the ruminant sector. Given the rapid rates of productivity growth observed recently, non-ruminant and crop productivity in developing countries may be converging to the productivity levels of developed countries. For ruminants, the results show that productivity levels may be diverging between developed and developing countries.

2. Productivity Measurement Methodology and Data

2.1 Directional Distance Functions and the Malmquist Index

The Malmquist index is based on the idea of a function that measures the distance from a given input/output vector to the technically efficient frontier along a particular direction defined by the relative levels of the alternate outputs. Nin et al. (2003) modify the directional distance function measure (Chung, Färe and Grosskopf, 1997) for use in the measurement of agricultural sub-sector productivity. There are two features that distinguish their work from the general directional distance measure. The first is that the direction of expansion of outputs and contraction of inputs increases only the *i*th output while holding all other outputs and all inputs constant. The second is that physical inputs that can be allocated across outputs are treated as different inputs. That is, allocatable inputs are constrained individually by output, and inputs that are not allocable are constrained in aggregate. For example, land in pasture is a livestock input and cropland is a crops input.

Following Färe et al. (1994), the product-specific directional Malmquist TFP index measures the TFP change between two data points by calculating the ratio of the distances to the frontier for a particular period of each data point. Nin et al. (2003) take advantage of information on input allocation by introducing specific input constraints for allocated inputs, modifying the directional distance function measure (Chung, Färe and Grosskopf, 1997). In general, the distance function is defined simultaneously as the contraction of inputs and the expansion of output ($-\boldsymbol{g}_x\ \boldsymbol{g}_y$), which in the case of an single output oriented measure, is denoted by $g=(y_i,\mathbf{0})$. The distance function $D(\mathbf{x},\mathbf{y};g=(y_i,\mathbf{0}))$, is the optimal objective value for the following problem:

$$
\begin{aligned}
&\max_{z^k,\beta_i^{k*}} \beta_i^{k*} \\
&\text{subject to} \\
&\sum_{k=1}^{N} z^k y_j^k \ge y_j^{k*} && i \ne j \ \text{ and } \ j=1,2,\ldots,J \\
&\sum_{k=1}^{N} z^k y_i^k \ge y_i^{k*}\left(1+\beta_i^{k*}\right) \\
&\sum_{k=1}^{N} z^k x_{hj}^k \le x_{hj}^{k*} && h \in A \\
&\sum_{k=1}^{N} z^k x_h^k \le x_h^{k*} && h \notin A \\
&z^k \ge 0 && k=1,\ldots,N
\end{aligned}
$$

where k is the set of countries (k^* is the particular country for which the distance measure is being applied), j is the set of outputs, h is the set of inputs, z^k is the weight on the kth country data, A is the set of allocatable inputs, x_{hj}^k is the level of the allocatable input h used to produce output j of country k, i is the particular output for which efficiency is being measured for country k^*, $i \ne j$ indexes the other outputs (for which efficiency is not being measured), and β is a scalar.

Based on the modified distance function, the product specific Malmquist index between period s (the base period) and period t is defined as the geometric mean of two Malmquist indexes, one evaluated with respect to period s technology and one with respect to period t technology:

$$DM(s,t)=\left[\frac{\left(1+\vec{D}_0^s\left(x^t,y_i^t,y_{-i}^t;y_i^t,\mathbf{0}\right)\right)}{\left(1+\vec{D}_0^s\left(x^s,y_i^s,y_{-i}^s;y_i^s,\mathbf{0}\right)\right)}\cdot\frac{\left(1+\vec{D}_0^t\left(x^t,y_i^t,y_{-i}^t;y_i^t,\mathbf{0}\right)\right)}{\left(1+\vec{D}_0^t\left(x^s,y_i^s,y_{-i}^s;y_i^s,\mathbf{0}\right)\right)}\right]^{0.5} \quad (1)$$

where $\vec{D}_0^s\left(x^t,y^t\right)$ represents the distance from the period t observation to the period s frontier. The output specific Malmquist index in (1) indicates that we measure TFP growth for output y^s_i, while holding all other outputs y^s_{-i} constant[1]. As with the Malmquist index, a value greater than one indicates an increase in productivity from period s to t.

There are two important limitations of the directional Malmquist Index which must be noted at this point. The first is the case where the distance function takes on the value of -1, in which case the Malmquist index is infeasible. Appendix Table B summarizes the degree of occurrence of this phenomenon. The second limitation derives from the fact that there might be a factor reallocation bias in the measure, that is, we might mistake the movement of unallocated inputs from one activity to the other for technological progress in the benefiting activity.

Similar to the general Malmquist Index, the directional Malmquist Index is decomposed into an efficiency component (catching-up) and a technical change component (changes in the production frontier):

$$DEFF(s,t)=\frac{\left(1+\vec{D}_0^t\left(x^t,y_i^t,y_{-i}^t;y_i^t,\mathbf{0}\right)\right)}{\left(1+\vec{D}_0^s\left(x^s,y_i^s,y_{-i}^s;y_i^s,\mathbf{0}\right)\right)} \quad (2)$$

$$DTECH(s,t)=\left[\frac{\left(1+\vec{D}_0^s\left(x^s,y_i^s,y_{-i}^s;y_i^s,\mathbf{0}\right)\right)}{\left(1+\vec{D}_0^t\left(x^s,y_i^s,y_{-i}^s;y_i^s,\mathbf{0}\right)\right)}\cdot\frac{\left(1+\vec{D}_0^s\left(x^t,y_i^t,y_{-i}^t;y_i^t,\mathbf{0}\right)\right)}{\left(1+\vec{D}_0^t\left(x^t,y_i^t,y_{-i}^t;y_i^t,\mathbf{0}\right)\right)}\right]^{0.5} \quad (3)$$

How much closer a country gets to the world frontier is called "catching-up" and how much the world frontier shifts at each country's observed input mix is called "technical change" or "innovation". Once a country catches-up to the frontier, further growth is limited by the rate of innovation, or movement of the frontier itself.

2.2 Data

Data for inputs and outputs were collected principally from FAOSTAT 2004 and covered a period of 40 years from 1961 to 2001. The data included 116 countries (see Table 1 for a complete listing) considering three outputs (crops, ruminants and non-ruminants), and nine inputs (feed, animal stock, pasture, land under crops, fertilizer, tractors, milking machines, harvesters and threshers, and labor). Nin et al. (2003) note that

[1] We calculate the distance functions between period *s* and period *t* required to estimate the Malmquist index by solving four linear programming (LP) problems.

there are two limitations with these data. First, there is limited information on prices, and second, input usage is not allocated across activities in agriculture. For this reason, the data are well-suited to use in conjunction with the product-specific distance measure. This allows the estimation of productivity growth by sub-sector given the inputs used and the output of all other sectors given these data limitations.

Table 1. Countries in FAO data by region

1. Industrialized Countries
Australia, Austria, Benelux, Canada, Denmark, Finland, France, Germany, Greece, Iceland, Ireland, Israel, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, UK, USA
2. Economies in Transition
Albania, Bulgaria, Czech Rep., Slovakia, Hungary, Poland, Romania, former USSR, former Yugoslav SFR
3. China
4. East & South East Asia
Cambodia, Indonesia, Korea D P Rep., Korea Rep, Laos, Malaysia, Mongolia, Myanmar, Philippines, Singapore, Thailand, Viet Nam
5. Asia Developing
Bangladesh, Bhutan, China, Cambodia, India, Indonesia, Iran, Iraq, Jordan, Korea D P Rp, Korea Rep, Laos, Lebanon, Malaysia, Mongolia, Myanmar, Nepal, Pakistan, Philippines, Saudi Arabia, Singapore, Sri Lanka, Syria, Thailand, Turkey, Vietnam, Yemen
6. Middle East and North Africa
Algeria, Egypt, Iran, Iraq, Jordan, Lebanon, Libya, Morocco, Saudi Arabia, Sudan, Syria, Tunisia, Turkey, Yemen
7. Sub-Saharan Africa
Angola, Benin, Botswana, Burkina Faso, Burundi, Cameroon, Cape Verde, Central African Rep, Chad, Congo, Dem R, Congo, Rep, Cote d'Ivoire, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Lesotho, Liberia Madagascar, Malawi, Mali, Mauritania, Mozambique, Namibia Niger, Nigeria, Rwanda, Senegal, Sierra Leone, Somalia, Sudan, Swaziland, Tanzania, Togo, Uganda, Zambia, Zimbabwe
8. Latin America & Caribbean
Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Rp, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Honduras, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Puerto Rico, Suriname, Trinidad & Tobago, Uruguay, Venezuela

Source: FAO

To estimate the disaggregate TFP measures for crops, ruminants and non-ruminants, we assume five allocatable inputs: land under crops is allocated to crops, ruminant stock and milking machines to ruminants, and non-ruminant stock to non-ruminants. In addition, feed is allocated to livestock but cannot be allocated between ruminants and non-ruminants. All other inputs remain unallocatable to outputs. The description of both inputs and outputs follow:

2.2.1 Outputs

The quantity of crop production is in millions of 1990 international dollars. FAO's crop production index estimated for each country is scaled using the value of crop output for 1990. The quantity of livestock production is in millions of 1990 international dollars. Output aggregates for ruminants and non-ruminants are built using international prices from Rao (1993, table 5.3). The 1990 output series were extended to cover the 1961-2001 period using the FAO production index. Livestock production is in millions of 1990 international dollars. Production indices for ruminants and non-ruminants were estimated using the same methodology as FAO, and using data from Rao (1993). Appendix A contains a detailed description on how we built output values for ruminant and non-ruminants.

2.2.2 Inputs

2.2.2.1 Animal Stock

Animal stock is the number of cattle, sheep, goat, pigs, chicken, turkeys, ducks and geese expressed in livestock unit (LU) equivalent. Given the variability of body sizes of the main animal species across geographical regions, animal units are standardized for comparisons across the world. Carcass weight statistics from 2000 are used to generate conversion factors for several regions around the globe, and used to convert stock quantities into livestock units using OECD cattle as the unit of measure. Cattle, sheep and goat stock were aggregated to form ruminant stock. Chicken, turkeys, ducks and geese were aggregated to form poultry stock. Poultry stock was aggregated with pig stock to form non-ruminant stock. For a more detailed discussion on how this variable is built, please refer to Appendix A.

2.2.2.2 Animal Feed

The amount of feed is expressed in metric tons of total protein supplied to livestock per year. Amounts of edible commodities (cereals, bran, oilseeds, oilcakes, fruits, vegetables, roots and tubers, pulses, molasses, animal fat, fish, meat meal, whey, milk, and other animal products from FAOSTAT food balance sheets) fed to livestock during the reference period, are transformed into protein quantities using information of feed protein content for each commodity. For a more detailed discussion on how this variable is built, please refer to Appendix A.

2.2.2.3 Machinery

There are three types of machinery used as inputs: Tractors, harvesters and threshers and milking machines, expressed as the total number in use. Tractors refer to total number of wheel and crawler tractors (excluding garden tractors) used in agriculture. We do not make any allowance for the horsepower of the tractors. Harvesters and threshers refer to the number of self-propelled machines that reap and thresh in one operation. Milking machines refer to the total number of installations consisting of several units, each composed of a pail, a pulsator and four-teat cups and liners.

2.2.2.4 Labor

The total economically active population in agriculture (in thousands), engaged in or seeking work in agriculture, hunting, fishing, or forestry, whether as employers, own-account workers, salaried employees or unpaid workers assisting in the operation of a family farm or business. This measure of agricultural labor input, also used in other cross country studies is an uncorrected measure, that does not account for hours worked or labor quality (education, age, experience, etc.).

2.2.2.5 Land

It is expressed in 1,000 Hectares, and includes: Land under crops is the land under temporary crops (doubled-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens, land temporarily fallow (less than five years), land cultivated with permanent crops such as flowering shrubs (coffee), fruit trees, nut trees, and vines but excludes land under trees grown for wood or timber. Pasture land includes land used permanently (five years or more) for herbaceous forage crops, either cultivated or growing wild (wild prairie or grazing land).

2.4.2.6 Fertilizer

Fertilizer is defined as the quantity of nitrogen, phosphorus, and potassium (N, P, K) in metric tons of plant nutrient consumed in agriculture by a country.

3. Total Factor Productivity Growth: Historical Results

The results of our TFP calculations are summarized in Table 2. We focus on historical productivity measurement and forecasts for 8 regions of the world, as shown by the groupings of countries in Table 1. The three agricultural sub-sectors for which we report directional TFP measures are: crops, ruminants and non-ruminants. For each agricultural sub-sector we report in Table 2 the average change in TFP, as well as the change in efficiency (EFF) and technical change (TCH) derived from the directional Malmquist index, by decade, as well as for the full 40 year period.

Table 2. Historical and Projected Average Total Factor Productivity Growth Rates by Region and Sector, 1961-2040 (%)

Regions / Sectors	Period	Crops			Ruminants			Non-Ruminants			Weighted Average		
		TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH
World	**1961-00**	***0.72***	***-0.03***	***0.75***	***0.62***	***-0.03***	***0.65***	***2.10***	***-1.08***	***3.23***	***0.94***	***-0.22***	***1.17***
	1961-70	1.14	-0.12	1.26	0.00	-0.88	0.89	2.31	-0.04	2.35	1.11	-0.26	1.38
	1971-80	-0.14	-0.82	0.68	0.31	-0.39	0.70	0.72	-1.39	2.16	0.11	-0.83	0.95
	1981-90	0.57	0.16	0.41	1.13	0.70	0.43	2.71	-3.09	6.08	1.06	-0.31	1.42
	1991-00	1.33	0.68	0.65	1.06	0.50	0.57	2.72	0.27	2.43	1.52	0.57	0.95
	2001-40	***0.94***	***0.22***	***0.71***	***0.82***	***0.17***	***0.65***	***3.60***	***0.92***	***2.64***	***1.38***	***0.34***	***1.04***
	2001-10	1.30	0.56	0.74	1.13	0.48	0.65	4.64	1.52	3.05	1.86	0.71	1.13
	2011-20	0.97	0.25	0.71	0.87	0.22	0.65	3.81	1.11	2.66	1.45	0.40	1.04
	2021-30	0.79	0.09	0.70	0.70	0.05	0.65	3.16	0.70	2.43	1.19	0.19	1.00
	2031-40	0.70	0.00	0.70	0.60	-0.05	0.65	2.79	0.34	2.43	1.05	0.05	1.00
Industrialized Countries	**1961-00**	***1.47***	***0.53***	***0.93***	***0.71***	***0.05***	***0.66***	***1.23***	***-0.36***	***1.61***	***1.19***	***0.20***	***0.99***
	1961-70	2.19	1.36	0.80	0.52	0.01	0.51	1.10	0.15	0.95	1.46	0.70	0.75
	1971-80	1.75	0.59	1.15	1.15	0.54	0.61	1.48	0.35	1.12	1.51	0.52	0.98
	1981-90	0.69	-0.15	0.84	0.67	-0.08	0.76	0.95	-1.78	2.84	0.74	-0.47	1.23
	1991-00	1.25	0.33	0.91	0.50	-0.27	0.78	1.39	-0.14	1.54	1.05	0.05	1.00
	2001-40	***1.14***	***0.21***	***0.93***	***0.27***	***-0.39***	***0.66***	***0.63***	***-0.94***	***1.61***	***0.77***	***-0.21***	***0.99***
	2001-10	1.50	0.56	0.93	0.36	-0.30	0.66	0.79	-0.79	1.61	1.01	0.02	0.99
	2011-20	1.13	0.20	0.93	0.30	-0.36	0.66	0.68	-0.89	1.61	0.79	-0.20	0.99
	2021-30	1.00	0.07	0.93	0.25	-0.41	0.66	0.58	-0.99	1.61	0.68	-0.30	0.99
	2031-40	0.95	0.02	0.93	0.19	-0.47	0.66	0.48	-1.08	1.61	0.62	-0.36	0.99
Economies in Transition	**1961-00**	***1.13***	***-0.24***	***1.38***	***0.28***	***-0.19***	***0.47***	***1.20***	***-0.68***	***1.91***	***0.89***	***-0.29***	***1.19***
	1961-70	1.40	-0.04	1.44	0.30	-0.20	0.51	1.07	-0.63	1.73	1.04	-0.17	1.21
	1971-80	-0.38	-1.12	0.77	-0.18	-0.43	0.25	0.43	-0.82	1.28	-0.21	-0.88	0.69
	1981-90	0.85	-0.19	1.05	0.54	0.27	0.27	0.45	-1.82	2.38	0.70	-0.29	1.01
	1991-00	2.72	0.42	2.28	0.47	-0.38	0.85	2.90	0.58	2.28	2.09	0.21	1.86
	2001-40	***1.39***	***0.49***	***0.89***	***0.53***	***0.06***	***0.47***	***2.09***	***0.61***	***1.45***	***1.24***	***0.38***	***0.85***
	2001-10	2.14	0.90	1.20	0.55	0.08	0.47	2.57	0.76	1.77	1.74	0.64	1.07
	2011-20	1.46	0.56	0.89	0.54	0.07	0.47	2.15	0.66	1.46	1.29	0.43	0.85

	2021-30	1.07	0.32	0.74	0.53	0.06	0.47	1.87	0.56	1.29	1.02	0.28	0.74
	2031-40	0.92	0.17	0.74	0.52	0.05	0.47	1.77	0.47	1.29	0.92	0.18	0.74
China	**1961-00**	***0.74***	***-0.06***	***0.80***	***2.82***	***1.85***	***0.95***	***3.33***	***-1.88***	***5.31***	***1.67***	***-0.47***	***2.17***
	1961-70	2.22	-0.25	2.48	0.27	-2.59	2.93	4.32	0.46	3.84	2.71	-0.20	2.92
	1971-80	-2.24	-2.81	0.59	-2.01	-2.75	0.76	-0.50	-3.64	3.27	-1.70	-3.06	1.41
	1981-90	0.93	0.84	0.09	7.12	6.99	0.12	5.36	-5.09	11.01	2.71	-0.51	3.39
	1991-00	2.11	2.06	0.05	6.22	6.19	0.03	4.26	0.91	3.33	3.05	2.01	1.04
	2001-40	***1.45***	***0.64***	***0.80***	***3.01***	***2.04***	***0.95***	***6.60***	***2.58***	***3.91***	***3.11***	***1.33***	***1.75***
	2001-10	2.23	1.42	0.80	5.84	4.84	0.95	8.83	3.76	4.88	4.47	2.37	2.04
	2011-20	1.50	0.69	0.80	3.22	2.24	0.95	7.02	2.96	3.94	3.29	1.49	1.76
	2021-30	1.12	0.32	0.80	1.81	0.85	0.95	5.65	2.16	3.42	2.54	0.91	1.60
	2031-40	0.95	0.15	0.80	1.25	0.29	0.95	4.93	1.46	3.42	2.17	0.55	1.60
East & South East Asia	**1961-00**	***0.02***	***-0.38***	***0.40***	***-0.22***	***-0.90***	***0.69***	***1.25***	***-1.51***	***2.82***	***0.18***	***-0.56***	***0.75***
	1961-70	0.27	-0.56	0.84	-0.15	-1.58	1.46	1.96	0.10	1.86	0.48	-0.52	1.01
	1971-80	0.99	0.40	0.59	1.16	0.63	0.52	1.52	0.00	1.52	1.07	0.36	0.71
	1981-90	-0.67	-0.85	0.18	-1.91	-2.20	0.30	1.02	-4.22	5.54	-0.49	-1.38	0.93
	1991-00	-0.48	-0.50	0.02	0.05	-0.41	0.46	0.53	-1.84	2.42	-0.32	-0.68	0.37
	2001-40	***-0.66***	***-1.06***	***0.40***	***-1.24***	***-1.91***	***0.69***	***3.67***	***0.84***	***2.80***	***-0.08***	***-0.83***	***0.75***
	2001-10	-0.51	-0.91	0.40	-1.15	-1.82	0.69	3.77	0.90	2.84	0.06	-0.70	0.76
	2011-20	-0.61	-1.01	0.40	-1.22	-1.88	0.69	3.76	0.86	2.87	-0.03	-0.79	0.76
	2021-30	-0.71	-1.11	0.40	-1.27	-1.94	0.69	3.59	0.82	2.75	-0.14	-0.88	0.74
	2031-40	-0.80	-1.20	0.40	-1.31	-1.98	0.69	3.55	0.77	2.75	-0.22	-0.96	0.74
South Asia	**1961-00**	***0.17***	***-0.22***	***0.39***	***0.35***	***-0.12***	***0.47***	***1.89***	***-0.77***	***2.69***	***0.27***	***-0.21***	***0.48***
	1961-70	-0.13	-1.08	0.97	-0.97	-1.73	0.78	2.23	0.70	1.51	-0.24	-1.17	0.95
	1971-80	-0.62	-0.96	0.34	-0.40	-0.73	0.34	0.02	-1.74	1.81	-0.55	-0.93	0.39
	1981-90	0.38	0.23	0.15	1.36	1.34	0.02	3.01	-2.06	5.23	0.69	0.41	0.29
	1991-00	1.07	0.96	0.10	1.43	0.68	0.74	2.32	0.05	2.27	1.19	0.87	0.32
	2001-40	***0.96***	***0.57***	***0.39***	***1.48***	***1.00***	***0.47***	***3.48***	***0.96***	***2.49***	***1.16***	***0.68***	***0.48***
	2001-10	1.07	0.68	0.39	1.65	1.18	0.47	3.75	1.08	2.63	1.29	0.80	0.48
	2011-20	1.00	0.60	0.39	1.54	1.06	0.47	3.53	1.00	2.49	1.20	0.72	0.48
	2021-30	0.93	0.53	0.39	1.42	0.94	0.47	3.37	0.92	2.41	1.12	0.64	0.47
	2031-40	0.86	0.47	0.39	1.30	0.82	0.47	3.28	0.84	2.41	1.04	0.56	0.47

Middle East & North Africa	**1961-00**	***-0.03***	***-0.24***	***0.21***	***-0.02***	***-0.54***	***0.52***	***0.64***	***-0.22***	***0.87***	***0.03***	***-0.30***	***0.34***
	1961-70	-0.22	-0.57	0.35	-0.20	-0.80	0.61	0.74	0.03	0.72	-0.13	-0.57	0.44
	1971-80	-0.07	-0.32	0.25	0.56	-0.07	0.63	1.55	0.61	0.92	0.21	-0.18	0.39
	1981-90	0.33	0.16	0.17	-0.03	-0.42	0.39	0.37	-0.51	0.90	0.26	-0.02	0.28
	1991-00	-0.15	-0.23	0.08	-0.40	-0.84	0.45	-0.08	-0.99	0.94	-0.19	-0.43	0.24
	2001-40	***0.45***	***0.23***	***0.21***	***-0.31***	***-0.83***	***0.52***	***-0.28***	***-1.12***	***0.87***	***0.22***	***-0.12***	***0.34***
	2001-10	0.47	0.25	0.21	-0.21	-0.72	0.52	-0.16	-1.01	0.87	0.26	-0.07	0.34
	2011-20	0.45	0.24	0.21	-0.28	-0.80	0.52	-0.25	-1.10	0.87	0.23	-0.10	0.34
	2021-30	0.44	0.22	0.21	-0.35	-0.86	0.52	-0.32	-1.17	0.87	0.20	-0.13	0.34
	2031-40	0.42	0.21	0.21	-0.41	-0.92	0.52	-0.38	-1.22	0.87	0.17	-0.16	0.34
Sub Saharan Africa	**1961-00**	***0.15***	***-0.08***	***0.22***	***0.36***	***-0.03***	***0.40***	***0.50***	***-0.25***	***0.76***	***0.21***	***-0.08***	***0.29***
	1961-70	-0.34	-0.78	0.45	-0.10	-0.69	0.60	0.61	0.19	0.42	-0.24	-0.71	0.47
	1971-80	-0.80	-0.96	0.16	0.58	0.04	0.54	0.62	0.49	0.13	-0.44	-0.67	0.23
	1981-90	0.89	0.76	0.13	0.26	-0.15	0.42	0.67	-0.64	1.32	0.75	0.49	0.26
	1991-00	0.86	0.70	0.16	0.72	0.69	0.03	0.10	-1.04	1.15	0.79	0.59	0.20
	2001-40	***0.91***	***0.68***	***0.22***	***0.57***	***0.17***	***0.40***	***-0.05***	***-0.80***	***0.76***	***0.78***	***0.49***	***0.29***
	2001-10	1.09	0.86	0.22	0.57	0.18	0.40	-0.01	-0.75	0.76	0.92	0.63	0.29
	2011-20	0.96	0.74	0.22	0.57	0.17	0.40	-0.04	-0.79	0.76	0.82	0.53	0.29
	2021-30	0.84	0.62	0.22	0.57	0.17	0.40	-0.07	-0.81	0.76	0.73	0.44	0.29
	2031-40	0.73	0.51	0.22	0.56	0.17	0.40	-0.10	-0.84	0.76	0.65	0.36	0.29
Latin America & Caribbean	**1961-00**	***0.76***	***-0.33***	***1.10***	***0.08***	***-0.78***	***0.87***	***2.01***	***-0.87***	***2.91***	***0.77***	***-0.53***	***1.30***
	1961-70	0.38	-0.73	1.12	-0.88	-2.28	1.44	0.29	-2.51	2.89	0.05	-1.38	1.46
	1971-80	0.53	-0.34	0.87	-0.02	-1.74	1.75	2.68	-0.36	3.06	0.70	-0.70	1.41
	1981-90	0.51	0.02	0.49	0.49	0.27	0.22	1.64	-1.27	2.96	0.67	-0.11	0.78
	1991-00	1.61	-0.29	1.91	0.74	0.65	0.09	3.45	0.69	2.73	1.66	0.09	1.57
	2001-40	***0.62***	***-0.47***	***1.10***	***1.50***	***0.62***	***0.87***	***4.55***	***1.75***	***2.74***	***1.41***	***0.13***	***1.28***
	2001-10	0.66	-0.43	1.10	1.65	0.76	0.87	5.48	2.57	2.82	1.61	0.30	1.29
	2011-20	0.63	-0.46	1.10	1.54	0.66	0.87	4.82	2.00	2.75	1.47	0.18	1.28
	2021-30	0.61	-0.48	1.10	1.45	0.57	0.87	4.19	1.46	2.69	1.34	0.06	1.27
	2031-40	0.59	-0.50	1.10	1.36	0.48	0.87	3.72	0.99	2.69	1.24	-0.04	1.27

NOTE: Productivity growth rates for Agriculture estimated weighted shares of each sub-sector in agriculture in each period.

The regional measures presented in Table 2 were obtained by combining individual country observations with regional observations, where the latter are treated as separate observations, obtained by aggregating inputs and outputs in individual countries within the regions (Table 2) using value share weights. The reason for including these regions directly in our productivity measurement exercise stems from a technical limitation of the directional Malmquist Index -- it is not well defined in all cases. In these cases, the linear program used to calculate the index is infeasible. As a consequence of these infeasibilities, we cannot build up weighted productivity measures for each region, as other authors have done (Coelli and Rao, 2005). However, at the regional level, these infeasibilities do not appear, and so we are able to obtain a full time series for every region by including the aggregated regions, along with the individual countries in the sample, directly in the efficiency measurement exercise. In this way, the individual country observations serve to identify the production possibilities frontier for agriculture, while the technical efficiency and technological change indexes are simultaneously computed for individual countries and for regions, and reported only for the latter.

Let us begin with our estimates of agricultural productivity growth, worldwide, over the entire, 40 year historical period. The global productivity estimates in Table 2, as well as those for aggregate agriculture, have been created as an adjusted share-weighted sum of the individual regions' crops, ruminants, and non-ruminants productivity measures also reported in Table 2.[2] The shares used in this process are based on the value of production in the year 2001, as reported by the FAO, and these are given in Appendix Table C1. We adjust these directional measures by a region-specific adjustment factor (see Appendix Table C2) so that they are consistent with the aggregate agriculture productivity estimate calculated from the traditional Malmquist index. Not only does this ensure comparability with other studies of agricultural TFP, it also renders these estimates usable in projections frameworks that do not embody the directional productivity concept.

Obviously the historical aggregate would be more accurate if we used observed, annual value weights. However, these are not available over the projections period. Also, by changing the weights, we would complicate any attempts to compare the historical and projected aggregates. Not surprisingly, the Industrialized Countries and China dominate the 2001 shares used for aggregation purposes. They accounting for 28% and 23% of global agricultural output, respectively in 2001. China's agriculture is dominated by crops (63% of total value), whereas the Industrialized Countries have nearly a 50-50 split between crops and livestock.

[2] An alternative would be to estimate TFP for aggregate agriculture directly using the same distance function approach, only now non-directional (since there is only one output involved). This is the approach of Nin et al., for example. While this would offer a preferred estimate of aggregate agriculture productivity, it has a significant drawback for present purposes, namely it is inconsistent with our subsector measures. Therefore, we opt to report aggregate agricultural productivity using the weighted subsector measures in order to offer a more consistent analysis of TFP growth world wide, building up from the subsector level.

The top right hand corner in Table 2 suggests that global agricultural total factor productivity grew over the 1961-2001 period at an annual rate of 0.94%. Total factor productivity growth may be decomposed into that portion due to an outward shift in the production possibilities frontier and that due to the average degree of "catching-up" of individual regions to this dynamic frontier. From the entries in the top right hand corner of Table 2, it is clear that, taking into account the production-weighted averages of different regions/sub-sectors, the frontier in agriculture advanced more rapidly (1.17%/yr.) than individual regions' TFP, thereby leading to negative technical efficiency growth (-0.22%/yr.). World average TFP growth also appears to have been increasing over the past three decades, rising from 0.11%/year in the 1970's to 1.52%/year in the 1990's. As we will see below, this is due to accelerating productivity growth in those developing regions where substantial economic reforms have taken place since 1980: China, Eastern Europe and the Former Soviet Union, Sub-Saharan Africa and Latin America.

When we break up aggregate agricultural TFP growth into sub-sectors, we find that, for the world as a whole, non-ruminant productivity growth (2.1%/year) far out-stripped that in the other sub-sectors. This high rate of TFP growth has been fueled by a rapidly advancing frontier, with technological change estimated to be more than 3.2%/year over this forty year period. As a consequence, virtually all regions have fallen further away from the frontier (negative technical efficiency growth rates averaging -1.08%/year) over this period.

In the case of ruminants, the same general pattern as with non-ruminant livestock productivity growth exists, although growth in the frontier has been much slower, and the industrialized countries have, as a group, been marginally increasing their technical efficiency, although all other regions have been falling back from the frontier. Overall TFP growth in ruminants has been about 0.62% per year. For crops, TFP growth has been about 0.72% per year, with a somewhat more rapid growth in the frontier than for ruminants. Once again, all of the developing country regions have been falling away from the frontier, with the rate of catch-up in Industrialized Countries offsetting this so that the world average efficiency growth is almost zero.

Next, turn to the block of entries in Table 2 representing TFP growth rates in the Industrialized Countries. It is quite striking that in these countries, where the share of consumer expenditure on food is relatively low, and only a small portion of the labor force is employed in agriculture, productivity growth rates are much higher – indeed 40% above the world average (which includes these countries) for the historical period. This higher growth rate is fueled strongly by high TFP growth in the crops sub-sector (1.47%/year). This is an extraordinarily high rate of TFP growth for a mature sector in mature economies, and testifies to the enormous productivity of the public and private investments in agricultural research over the past half century in these countries.

Industrialized country TFP growth in the crops sector is followed in size by non-ruminants (1.23%/year) – although this rate of TFP growth is lower than the world average. (Industrialized countries account for one-third of the value of world output in non-ruminants.) The slowest rate of productivity growth in the industrialized countries' agricultural sector is for ruminants (0.71%/year). Even so, the ruminants TFP growth rate over this 40 year period is higher than for all other regions, with the exception of China, and fifteen percent higher than the world average TFP growth rate for ruminants.

The next region displayed in Table 2 represents the so-called "Economies in Transition" (EIT) which include Eastern Europe and the Former Soviet Union. As the name indicates, they represent a group of economies that have undergone very substantial changes in the past decade and a half. And their TFP growth record reflects this. Indeed, the decade of the 70's shows negative TFP growth in this region. This is followed by some improvement in the 1980's and rapidly accelerating productivity growth in the 1990's, following the collapse of the Soviet Union and the opening up of the Eastern Bloc. This is acceleration is particularly striking in the case of crops and non-ruminant livestock production.

Productivity growth in China has been notoriously hard to measure due to the tendency for output statistics to be artificially inflated in order to meet pre-established planning targets. However, there is little doubt that the TFP performance of agriculture in China has been strengthening since the 1970's, when it declined at an average rate of nearly 2%/year. This improvement is particularly striking in the case of livestock production, where productivity growth in the 1980's and 1990's has been extraordinarily high. In the case of ruminant production, we attribute most of this TFP growth – between six and seven percent per year over the past two decades -- to "catching up". On the other hand, growth in non-ruminant productivity in China appears to have been driven by outward movement in the technological possibilities facing this sector.

China is followed in Table 2 by East and Southeast Asia. This regional grouping reflects FAO data on 14 countries, including much of ASEAN as well as both Koreas (see Table 1). As such, it is a rather heterogeneous grouping of economies, for which crop production is dominant (82% of the value of output – see Table C1). We estimate a very modest weighted rate of TFP growth for this region, just 0.18%/year, with negligible growth in crops TFP over the 1961-2001 period. In fact, in contrast to other regions, crop TFP appears to have fallen since the 1970's. Non-ruminant productivity growth is the only bright spot for this region, with a 1.25% growth rate over the 40 year historical period.

The next region in Table 2 is South Asia. Due to the fact that the efficiency series for this region were 1 for all years in the sample, it was not possible for us to model these series using the logistic function. To solve this problem, we estimated this block using a composite of all developing countries in Asia. So it includes the preceding two regions (China, East and Southeast Asia, as well as South Asia and several countries in the Near East). This is clearly a limitation of the present study, but it does permit us to obtain an exhaustive set of estimates for the world as a whole, which is our ultimate goal. For this region, we find slow, but positive productivity growth in crops and ruminant livestock, with faster growth in non-ruminants.

The Middle East and North Africa is the next region covered by our estimates in Table 2. Much like South and Southeast Asia, the lack of growth in crop and ruminant TFP leads to negligible aggregate productivity growth with non-ruminants being the only subsector with a reasonably strong performance over the historical period.

In contrast to the Middle East and North Africa, Sub Saharan Africa shows modest TFP growth across all three subsectors, with a marked improvement in crops productivity since the structural adjustment reforms of the 1980's. In fact, the overall weighted average rate of productivity growth for this region over the 1990's is 0.79% per year.

The Latin America & Caribbean region also shows accelerating growth in TFP – particularly in the 1990's when Brazil in particular undertook major rural sector reforms. This jump in TFP growth is most noticeable in crops and non-ruminants. The overall average rate of productivity growth across all subsectors is nearly 1.7%/year in this region over the 1991-2001 period.

4. Analysis of Historical Productivity Growth: Testing for Convergence

4. 1 Convergence testing and methodology

Productivity convergence occurs when the less developed economies experience faster TFP growth than their developed neighbors, therefore reducing the technological gap between them. The concept of convergence can be traced back to the Solow's (1957) neoclassical growth model which proposes that technological change is an exogenous process that can be transferred from developed to developing countries. More recently, the endogenous growth theory (Romer, 1986; Lucas, 1988) considers technological change as a dynamic process, reflecting structural differences across countries. This model allows for productivity growth (and income) to differ permanently across countries, arguing that there may not be convergence between developed and developing countries due to structural differences.

Convergence in agricultural productivity across countries has been tested by various authors. Suhariyanto and Thirtle (2001) find no evidence of convergence among 18 Asian countries. Schimmelpfennig and Thirtle (1999) and Rezitis (2005) find evidence of productivity convergence in agriculture between the US and European countries using time series tests. Rao and Coelli (2004) and Coelli and Rao (2005) find that countries that were less efficient in 1980 have a higher TFP growth rate than those countries that were on the frontier in 1980. They conclude that these results indicate a degree of catch-up due to improved technical efficiency along with growth in technical change. However, as can be seen from Figure 1, it makes little sense to test for convergence in aggregate agricultural TFP, given the wide differences in subsector performance.

Rae and Hertel (2000) examine subsector convergence, using partial factor productivity measures (livestock output per head) across a range of countries in the Asia-Pacific region. They find productivity convergence for pigs, poultry and ruminant productivity, but divergence for milk productivity. Of course this work is subject to the same criticism of all PFP measures, namely that it fails to distinguish between factor substitution and TFP growth. To the extent that increased output per head is due to higher feed use, TFP growth will be overstated.

There are two dominant approaches to testing for convergence: the cross section and the time series approaches. The cross section approach takes advantage of the tendency of developing economies to grow faster relative to the more developed economies. The time series approach (Bernard and Durlauf 1995; Bernard and Jones, 1996) is based on the properties of the productivity growth series. In this case, there is convergence if the productivity differences across countries tend to zero, as the forecasting horizon tends to infinity. That is, there is productivity equality across countries or regions.

However, the time series approach requires us to have explicit measures of the level of productivity, not just the rate of growth. Therefore, we are confined to looking at convergence in efficiency levels only (Cornwell and Watcher, 1999). Cornwell and Watcher argue that these efficiency levels can be interpreted as the county's ability to absorb technological innovations, and therefore represent productivity catch-up to the frontier by technology diffusion. This would allow us to test for convergence in the efficiency levels across regions.

We use these convergence tests to formally examine the hypothesis that there exists a common trend for subsector efficiency levels across regions. The first step in testing for convergence is to conduct augmented Dickey Fuller tests on each of the calculated efficiency series to determine their long-run properties. For those regions whose measured efficiency is non-stationary we proceed to the second step which involves testing for cointegration using the methodology developed in Johansen (1991) and Johansen and Juselius (1990). If a linear combination of two or more non-stationary series is stationary, then these series are said to be cointegrated. If the regionwise efficiency levels are cointegrated, that would indicate a long term relationship in the diffusion of technology between those regions. This is precisely the kind of link in TFP across regions for which we are looking.

4.2 Convergence Results

The augmented Dickey-Fuller tests (not shown here) indicate that, except for North America, Australia and New Zealand, and South Asia, the hypothesis of unit root non-stationarity at zero frequency cannot be rejected. Consequently, these series with suspected unit roots will be treated as non-stationary and potentially subject to cointegration. With the non-stationary series we apply cointegration tests, results for which are reported in

Table 3. This table contains the results of the cointegration tests for each pair of countries/regions for crops, ruminants and non-ruminants, in that order.

Table 3. Cointegration Results for Each pair of regions and countries for Crops, Ruminants and Non-Ruminants Efficiency Levels

Country/Region	World	Developed Countries	Developing Countries	Western Europe	Economies in Transition	North Africa and Middle East	East & South East Asia	Latin America	Sub-Saharan Africa
China	-,5,-	5,-,-	—	—	-,-,5	—	—	—	—
World		—	-,5,-	-,5,5	-,1,-	—	—	-,5,5	-,5,-
Developed Countries			—	-,-,5	-,-,5	—	—	1,-,5	—
Developing Countries				—	—	5,-,-	—	5,-,1	—
Western Europe					—	5,-,-	—	5,-,5	-,-,1
Economies in Transition						—	—	-,5,-	5,-,-
North Africa & Middle East							—	5,-,-	5,-,-
East & Southeast Asia								-,-,5	5,-,5
Latin America									5,-,1

*Each cell denotes the significance level of the cointegration test for crops, ruminants and non-ruminants, in that order. A dash denotes no cointegration. For example, in the pair Developed Countries/Latin America, 1,-,5 denotes cointegration at the 1% level for crops, no cointegration for ruminants and at the 1% level for non-ruminants.

Each cell in this table has three entries referring to the results of convergence tests for crops, ruminants, and non-ruminants, respectively. Consider, for example, the entries in the China row, under the second column of Table 3. Here, the 5 in the first entry denotes convergence with developed countries in crop productivity levels at 5% significance, but shows no cointegration (no entry) for ruminants and non-ruminants. In the case of Latin America, there is 1 in the first entry of the developed countries row, denoting convergence at the 1% significance level. This suggests a regular, long term pattern of technology diffusion of crop production technology from the developed countries to these two developing regions. There is also convergence of Sub-Saharan Africa’s crop TFP to the Economies in Transition, North Africa and the Middle East, Asia and Latin America.

For ruminants, the second entry in each cell of Table 3, most of the developing regions (China included) show convergence with the world average, although none show convergence with developed countries as a group. So, given the productivity growth rates that we have presented in this paper, there may well be divergence between developed and developing countries in ruminant production. This is consistent with the earlier findings of Rae and Hertel (2000), based on convergence tests using PFP measures.

For non-ruminants, the third entry in each cell, we observe that there is convergence of Economies in Transition and Latin America to developed countries, and, in the case of Latin America, convergence to Western Europe. Sub-Saharan Africa shows signs of convergence to various regions, including Europe, Asia and Latin America. These results may suggest that for developing countries, the growth in non-ruminant productivity is prompting them to catch up with developed countries.

5. Productivity Projections 2001-2040

5.1 Current Models

Before considering our own projections of agricultural productivity growth, it is useful to consider the approaches currently in use. One of the most widely cited models for forecasting future supply and demand of food products is the IMPACT model (Rosegrant et. al, 2001), which covers 18 commodities and 37 countries or country groups. Future supply in this model is based on changes in area, yield and production in crops, and for, in the case of livestock, changes in output per head and production. Productivity growth in this model is an exogenous trend factor in the PFP response function.

The USDA (2005) also makes projections of future supply and demand for agricultural products. They assume that historical growth trends in productivity hold for the period 2005-2014. The OECD-FAO Agricultural Outlook (2005) also assumes that productivity trends will continue over the period 2005-2014. They note that while production is projected to increase, some slowdown in the rate of growth is expected, matching the slowdown in population growth. They expect that production growth in developing countries outpaces that in OECD countries, especially for meat and dairy products.

5.2 Forecasting Methodology

In constructing our forecasts of future productivity levels in agriculture, we depart in two significant ways from this current "state of the art". First of all, rather than forecasting PFP, we forecast TFP, building on our historical measures of total factor productivity by the eight major regions of the world previously identified. Secondly, rather than simply extrapolating based on past trends, we recognize that there are two important contributors to historical productivity growth: technical change and technical efficiency, and these may behave quite differently over our forecast period. While we have no economic reason to argue against continued outward movement in the technology frontier in line with historical trends, we feel strongly that the process of "catching up" to the frontier, in which some developing countries are currently engaged, is unlikely to continue unabated. The simple reason for this is that in cases such as China's "catching up" to the frontier in ruminant livestock production, they will eventually reach the frontier. At that point, China's productivity growth may be expected to slow down, with future growth constrained by outward movement in the technological frontier.

To project changes in the technical efficiency component of TFP growth, we assume that technological catch-up can be modeled as a diffusion process of new technologies, where the cumulative adoption path follows an S-shaped curve (Griliches, 1957; Jarvis, 1981). This curve denotes that efficiency change at the beginning changes slowly because new technologies take some time to be adopted. As technology becomes more widely accepted, a period of rapid growth follows until it slows down again and reaches a stable ceiling. In this case, we assume that efficiency levels for all regions will eventually reach the production possibility frontier and become fully efficient.

We follow Nin et al. (2004) in modeling this adoption path using a logistic functional form to capture the catching up process for each of the countries/regions in the sample. Specifically, we use the following logistic function to represent the catching up process of each of the regions in the sample:

$$Z_{it} = \frac{K_t}{1+e^{-\alpha-\beta t}} \tag{4}$$

where Z_{it} is the efficiency level of region i in year t, K_t is the maximum efficiency level, which in our case is equal to 1 and constant, and the parameters α and β determine the shape of the logistic function. The speed of change of the function is given by the value of β, where a higher value of β denotes a faster rate of catching up to the frontier. The parameters of the logistic function are estimated by transforming the observed efficiency values as follows:

$$Y_{it} = \log\left(\frac{Z_{it}}{K_t - Z_{it}}\right) = \alpha + \beta t \tag{5}$$

Positive and significant estimates of β for a particular region will denote that this region is catching up to the frontier.

As in Nin et al. (2004), before estimating the logistic function, we perform Chow tests of structural breaks of the efficiency time series. With this, we account for historical changes in the efficiency series that may cause possible differences in the intercept or the slope or both. The estimates of the logistic function (Tables D1, D2 and D3) are then used to estimate the long run path of efficiency levels out to the year 2040.

We must also project the rate of technical change in future TFP growth. Here, we simply assume that countries grow at their historical trends. However, in the case of those regions with average growth rates higher than industrialized countries, the rate of future technical change is assumed to erode (linearly) over time so that it eventually falls to the rich country growth rate. In particular, we assume that, after 20 years, the regions with initial rates of technical change above the industrialized countries will be growing at the same rate as industrialized countries (otherwise, they would eventually exceed the productivity levels in the developed countries). Given the projected growth path of each of these two components of TFP, we calculate the TFP growth rates by multiplying the two components together, as was done with the calculation of the Malmquist index (equation 1).

5.3 Projection Estimates 2001-2040

The lower portion of each regional panel in Table 2 contains the total factor productivity, efficiency and technical change projections for each subsector in each region over the period: 2001- 2041, as well as by sub-period (2001-2010, 2011-2020, 2021-2030, and 2031-2040). The first thing to note is that the weighted average for the World is higher in the projections period than in the historical period for TFP (1.38%/year vs. 0.94%/year) and for all three agricultural subsectors. When we compare the component parts of TFP, we see that this difference is entirely due to the projected increase in technical efficiency over the next 40 years – and particularly over the next decade. This reflects a continuation of the improvements in efficiency observed between the 1980's and the 1990's. On the other hand, technical change is actually projected to be lower in the projections period – despite the fact that we are projecting this based on historical trends. This difference between the historical period and the projections period is due to the anticipated slowing down of the very high rate of technological change in a few key developing countries in the future as discussed in the preceding paragraph.

As we move to the left in the top panel of Table 2, we see which subsectors contribute the most to this higher rate of average TFP growth for agriculture. The overall average TFP growth rate for crops and ruminants is lower in the historical and projections period, with non-ruminants showing much higher TFP growth rates over the projections period. And, as anticipated above, this is fueled by high rates of "catching up" as predicted by our logistic model of technical efficiency. This catching up is particularly prominent in the first decade of the forecast period.

Next, consider the TFP forecasts for Industrialized Countries. Here, the growth rate is actually quite a bit lower than in the historical period (0.77% vs. 1.19% in the historical period) – as a consequence of a slower rate of technical efficiency growth. All three agricultural sectors show somewhat lower TFP growth in the industrialized countries over the forecast period. Overall, average agricultural TFP growth in these high income economies is lower in the forecast than in the historical period.

In the case of the Economies in Transition region, much of the historical TFP growth was attributed to technological progress. As a consequence, if we project these historical growth rates forward without modification, TFP in the EIT region would eventually overtake that in Western Europe and the United States. Therefore, we impose the condition that, by 2020, the rate of technological change in the EIT will have fallen to the rate observed for industrialized countries. Thus, for crops, the EIT rate of technological progress from 2021-2040 is just 0.74%/year. However, when combined with a higher rate of growth in technical efficiency, the resulting TFP growth rate for EIT exceeds that in Industrialized Countries.

China's TFP growth rate in the projections period is higher for all subsectors than for the historical period. Although, with the exception of non-ruminants, the TFP growth for the next 40 years is lower than that for the decade of the 1990's. Again, the main difference is the projected rate of growth in technical efficiency which is extremely high for ruminants (a very small sector in China, accounting for just 7% of total output). It is also high for non-ruminants where TFP growth over the past two decades has been in excess of 4%, as China makes the transition from back-yard pig and poultry production systems to modern, industrial production.

In East and Southeast Asia, projected weighted average productivity growth for all three subsectors is -0.08% with higher productivity growth rates (3.67%) for non-ruminants. The projections for South Asia, based on the entire Developing Asia region, are higher than the historical estimates, with the highest growth rates for non-ruminant livestock. For Middle East and North Africa, TFP for all three subsectors is projected to be 0.22%, with higher growth in crops (0.45%). In Sub-Saharan Africa average agricultural TFP growth over the next 40 years is projected to be just over three quarters of one percent, fueled by both outward shifts in the frontier and improved efficiency. Subsector TFP growth in non-ruminants is negative over the projections period, whereas TFP growth in crops is close to one percent per year.

Finally, for Latin America, average agricultural TFP growth is projected to be higher than historically, with the difference largely driven by livestock productivity growth. The weighted average of sub-sector productivities for this region is projected to grow at 1.61%/year over the 2001-2010 period, falling to 1.3%/year in the final 20 years, for an overall average of 1.41%/year. As with the other regions, this difference is largely due to a slowing down of efficiency growth as producers move closer to the frontier. The ordering of subsector growth rates also follows the other developing country regions, outside of Africa, with non-ruminant TFP growing fastest, followed by ruminants and then crops TFP growth.

Table 4 reports the contribution of each region to world TFP growth, by subsector for both the historical period and the projections period. These contributions represent the share-weighted TFP growth rates, by region, from Table 2, weighted by the 2001 production shares reported in Table C1. It is interesting to contrast the sources of global average growth between the last 40 years and the projected 40 year period (A decade-by-decade comparison is available in Appendix Tables E1 (historical) and E2 (projected); Specific region composition by sector and decade is available in Appendix Tables F1 (historical) and F2 (projected)). As noted previously, TFP growth in crops between the two periods is just 0.2%/year higher in the projected period. However, whereas industrialized countries accounted for 46% of this TFP growth over the 1961-2000 period, they account for only 28% of the global productivity growth in crops over the next 40 years (This uses constant – 2001 – production weights; if we were to use annual production weights, this difference would be even more striking). China's contribution to global crop TFP growth increases by 50%, while that in other developing countries also increases strongly.

In the case of ruminants, the shift in relative contributions is even more striking, with industrialized countries' share of growth falling from 47% to 14%. China, South Asia and Latin America make up the bulk of this difference. Overall, the average TFP growth rate for ruminants is also higher in the projections period. Asia as a whole accounts for about half of the efficiency gains in ruminant production, while almost half of the technical change gains are in industrialized countries. This indicates the leading role of industrialized countries as a source of technology in ruminant production, while most of the catching-up is in developing regions, especially Asia.

Table 4. Historical and Projected World Productivity Growth Shares by Region

Regions	Crops			Ruminants			Non-Ruminants		
	TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH
Productivity Growth 1961-2001	*0.72*	*-0.03*	*0.75*	*0.62*	*-0.03*	*0.65*	*2.10*	*-1.08*	*3.23*
Shares by Region (%)									
Industrialized Countries	46	-355	28	47	-67	42	20	11	17
Economies in Transition	13	57	15	5	78	9	4	4	4
China	24	39	24	35	-499	11	61	67	63
East & South East Asia	0	100	5	-1	47	2	3	7	5
South Asia	4	95	8	8	56	10	2	2	2
Middle East & North Africa	0	34	1	0	83	4	1	0	1
Sub Saharan Africa	1	14	2	3	5	3	0	0	0
Latin America & Caribbean	12	116	17	2	396	20	9	8	9
Total	100	100	100	100	100	100	100	100	100
Productivity Growth 2001-40	*0.94*	*0.22*	*0.71*	*0.82*	*0.17*	*0.65*	*3.60*	*0.92*	*2.64*
Shares by Region (%)									
Industrialized Countries	28	22	29	14	-91	42	6	-35	20
Economies in Transition	12	17	10	8	4	9	4	5	4
China	36	66	26	28	91	11	70	108	57
East & South East Asia	-6	-42	5	-2	-16	2	5	5	6
South Asia	15	38	8	24	77	10	2	2	2
Middle East & North Africa	2	5	1	-2	-21	4	0	-3	1
Sub Saharan Africa	6	19	2	3	5	3	0	-2	0
Latin America & Caribbean	8	-25	18	26	52	20	12	19	10
Total	100	100	100	100	100	100	100	100	100

Note: Historical and projected shares weighted by output value in 2001

In the case of non-ruminants, TFP growth is dominated by China, which accounts for 70% of the global average TFP growth in this sector (China's 2001 production share is 38%), and 108% of the growth in technical efficiency. The nature of pigs and poultry technology makes it easily transferable across countries. As China expands its production from a backyard system, which is the dominant production system now, to more specialized production systems, these structural changes in production will have important impacts on costs and technology transfer, which are reflected in these expected productivity and efficiency gains.

A useful way of summarizing the TFP information in Table 2 is via line graphs. We have done so in Figures 1 through 8, which display the cumulative Malmquist TFP index for each sub-sector, as well as for the overall average, for both the historical and projected periods. The first thing to note from these figures is the heterogeneity across subsectors in each region. Taking an average, or simply measuring TFP at the level of aggregate agriculture is highly misleading if one is attempting to understand changes in commodity supplies or input use over time. These figures also permit one, in the historical period, to more readily identify the impact of economic reforms – such as those in China in the late 1970's and those in Sub Saharan Africa in the mid-1980's.

These figures also underscore the dynamism of the non-ruminant livestock sector. In the past two decades, TFP growth rates in China have been extremely high, with South Asia and Latin America not far behind. If this "catching up" process continues in the next two decades, productivity in many parts of the world will reach that in the industrialized countries. Of course, not all the TFP projections are positive. With the exception of non-ruminants, East and South East Asian TFP falls over the projections period. The Middle East and North Africa – a region with very high population growth rates – shows little sign of increasing TFP in agriculture. And finally, given its potential for continued high rates of population growth, as well as its low level of productivity currently the relatively slow growth rate in agriculture TFP in Sub-Saharan Africa are also troubling. Without significant investments in research and extension infrastructure, it is unlikely that this trend can be reversed.

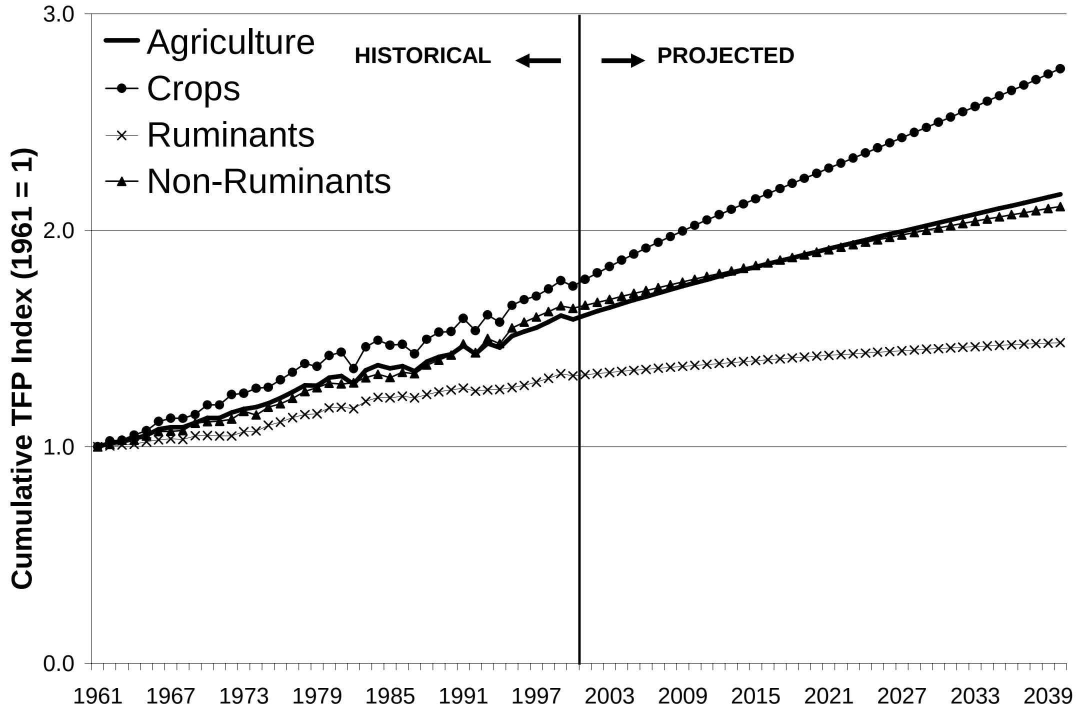

Figure 1. Cumulative Malmquist indexes for crops, ruminants and non-ruminants (1961-2040) in Industrialized Countries

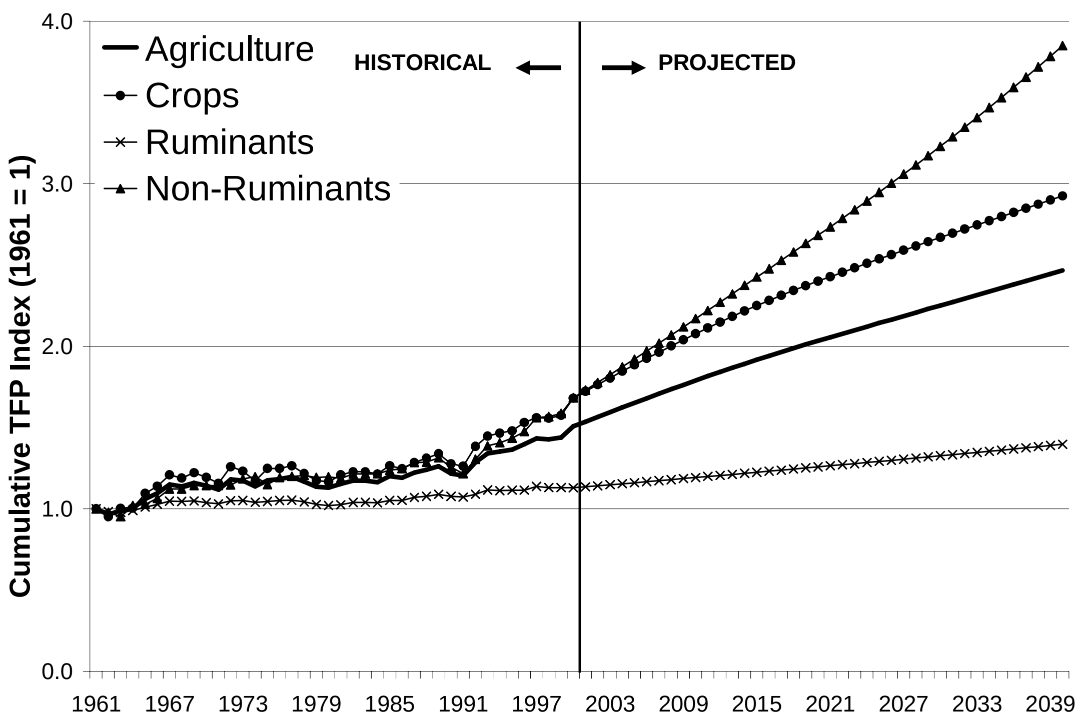

Figure 2. Cumulative Malmquist indexes for crops, ruminants and non-ruminants (1961-2040) in Transition Markets

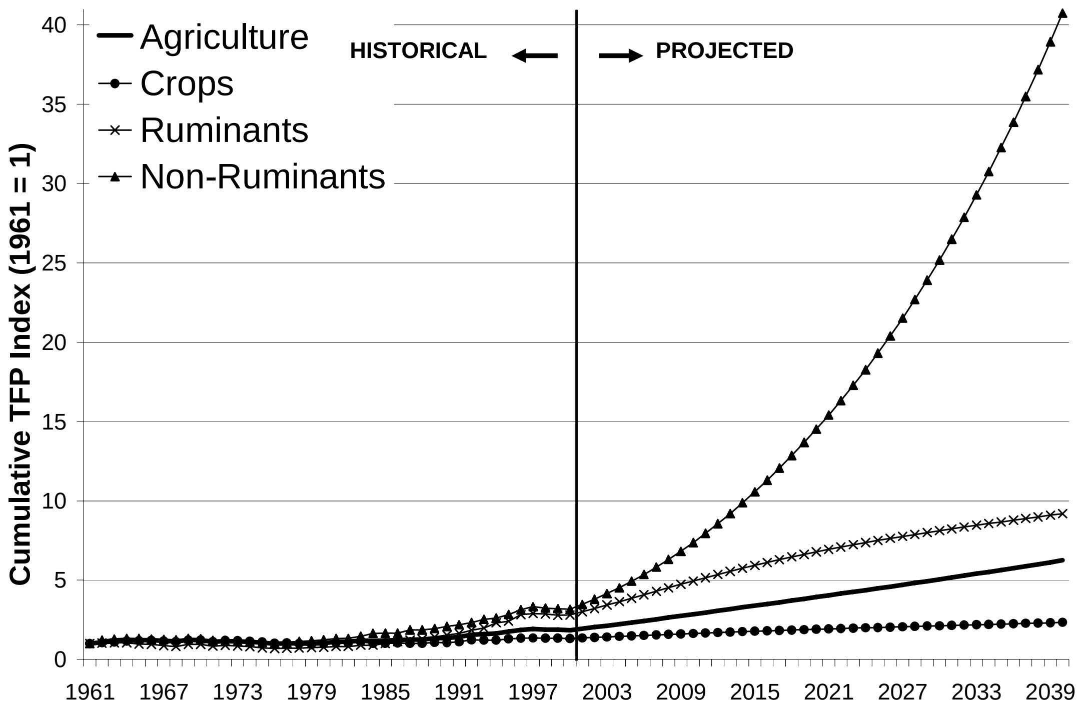

Figure 3. Cumulative Malmquist indexes for crops, ruminants and non-ruminants (1961-2040) in China

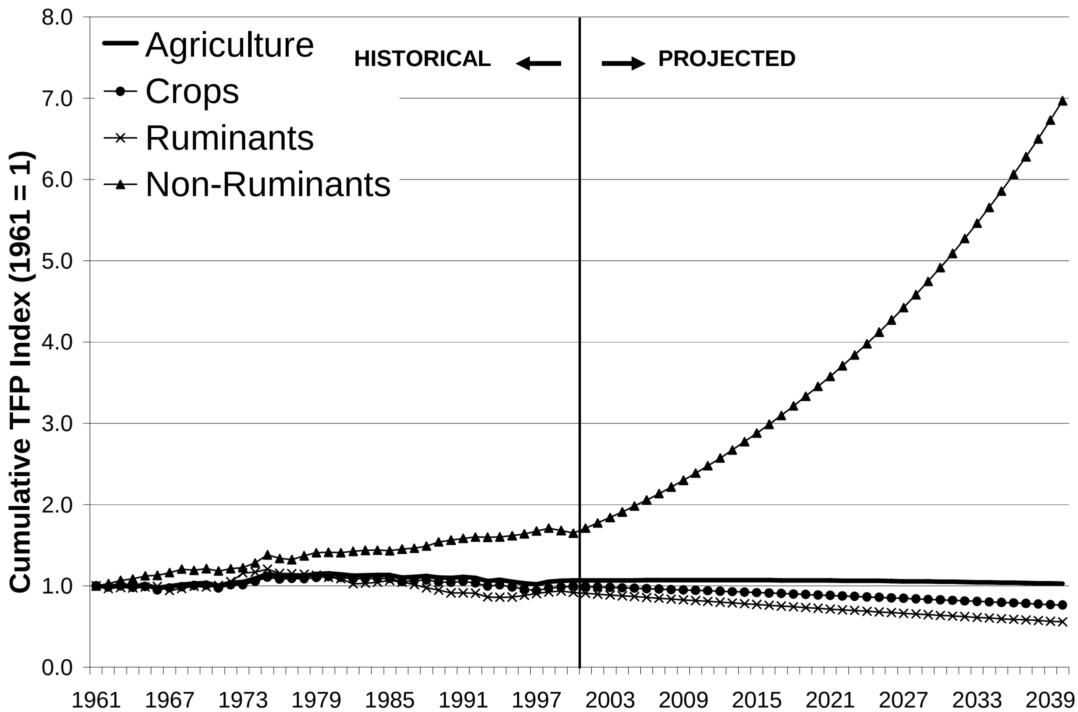

Figure 4. Cumulative Malmquist indexes for crops, ruminants and non-ruminants (1961-2040) in East and South East Asia

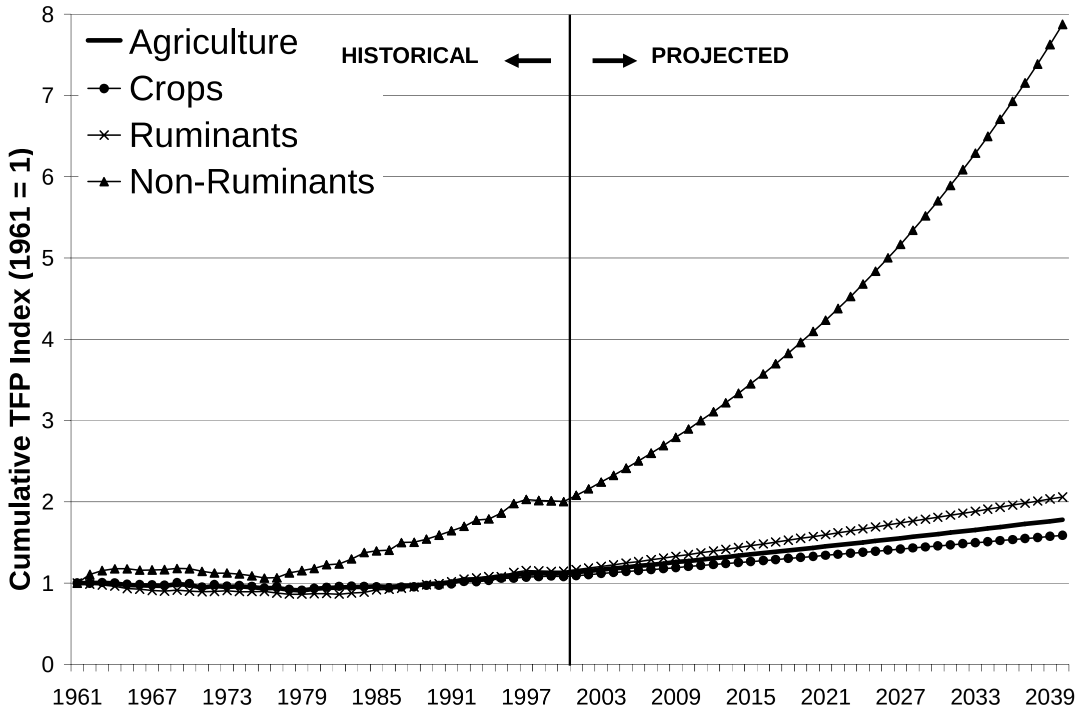

Figure 5. Cumulative Malmquist indexes for crops, ruminants and non-ruminants (1961-2040) in South Asia

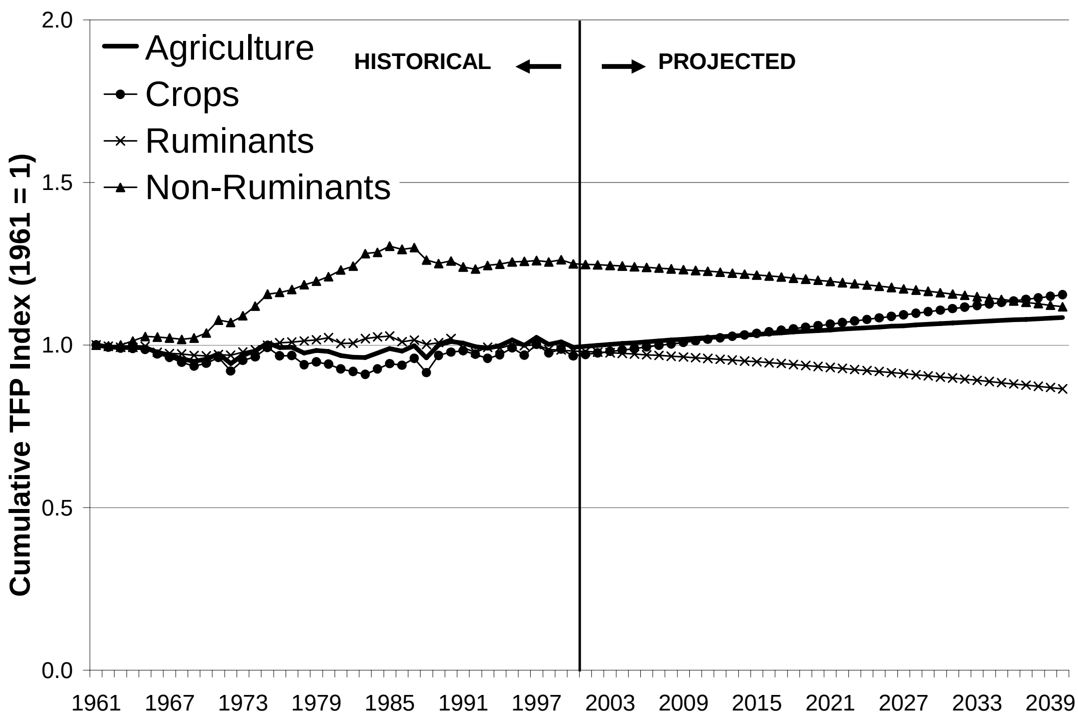

Figure 6. Cumulative Malmquist indexes for crops, ruminants and non-ruminants (1961-2040) in Middle East and North Africa

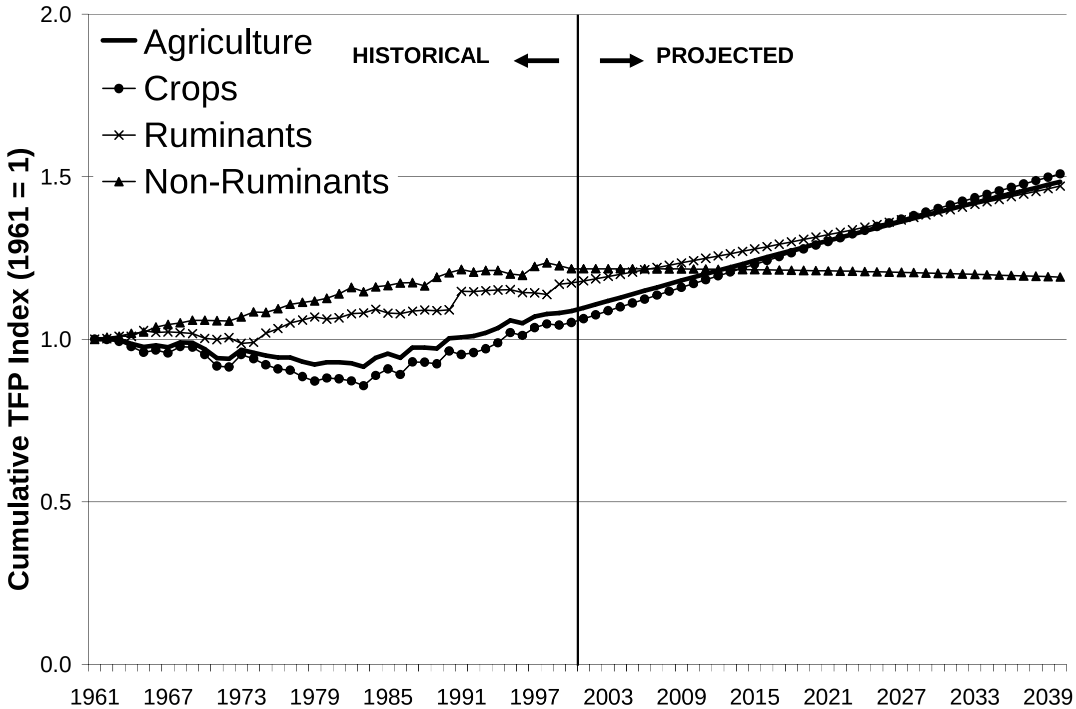

Figure 7. Cumulative Malmquist indexes for crops, ruminants and non-ruminants (1961-2040) in Sub-Saharan Africa

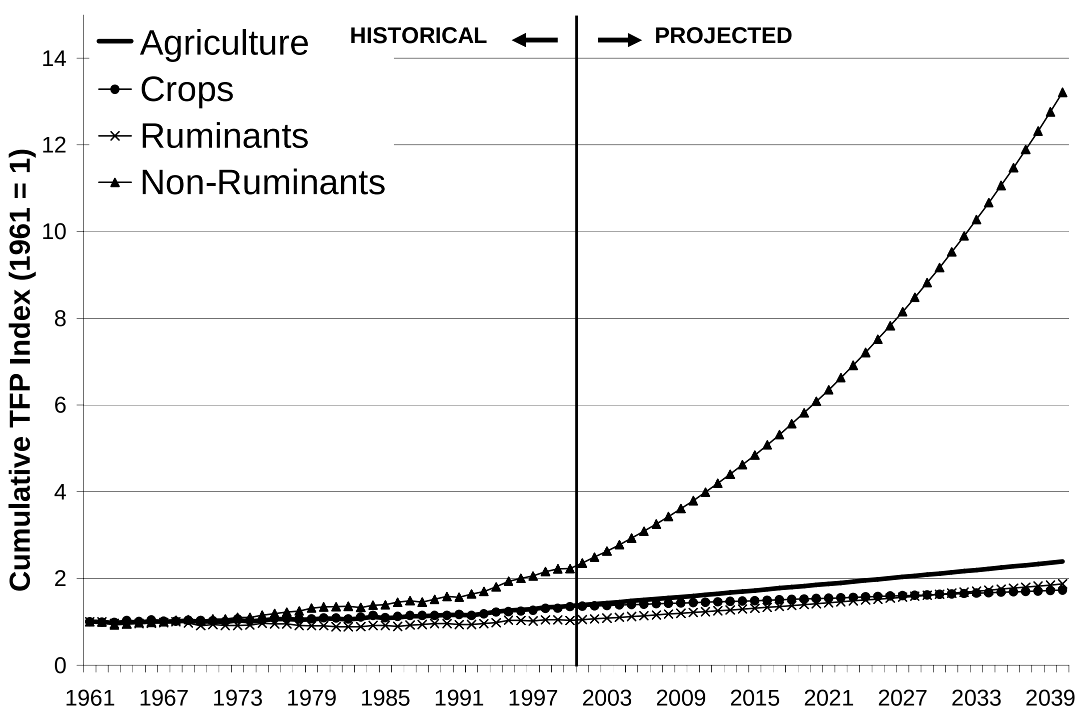

Figure 8. Cumulative Malmquist indexes for crops, ruminants and non-ruminants (1961-2040) in Latin America and the Caribbean

6. Summary and Implications for Forecasting Agricultural Growth and Input Use

Estimation of future food supply relies heavily of projections of future productivity growth in agriculture. The rate of productivity growth in agriculture is fundamental to forecasting global commodity markets, future patterns of international trade, and changes in land use. However, most of the current work relies on projections of yields and output per head of livestock, which, as PFP measures, are highly imperfect.

The contribution of this paper to the productivity measurement literature is that it provides TFP growth measures for crops, ruminants and non-ruminants, on a global basis, for the period 1961-2001. Additionally, it tests for convergence in technical efficiency and forecasts productivity growth of these three agricultural sub-sectors to the year 2040. These productivity forecasts are based on our analysis of historical productivity estimates, and account for technological diffusion across regions based on the convergence results.

The results indicate that developed countries have had greater historical productivity growth in crops and ruminant production than developing countries. However, developing regions show a much larger productivity growth rate in non-ruminant (pigs and poultry) production. The results indicate some degree of convergence between developing and developed countries in crops and non-ruminant production, but not so for ruminant production where there is evidence of technological divergence between developed and developing countries.

Our forecasts point to higher TFP growth in livestock in the developing world, while TFP growth in crops in the industrialized countries is forecast to exceed that for ruminants. The faster livestock TFP growth in developing countries is a positive development for consumers, given the relatively high income elasticities of demand for livestock products in the developing world. These future productivity growth rates also have important implications for land use, where more intensive use without additional inputs could further degrade its productivity. However, to evaluate these impacts, one needs an explicit simulation model, since an expanding livestock sector could also increase the demand for feedstuffs. The next stage of this research will incorporate these TFP estimates into a dynamic, global general equilibrium model in order to evaluate the impacts of such growth on international trade, land use, employment, and poverty.

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Appendix A: Data Sources and Manipulation

A1. Output Value

Value of output of crops and livestock in 1990 was collected from the Economic Research Service (ERS) website at http://usda.mannlib.cornell.edu/data-sets/international/89024/. These values were normalized using production indices (Production Index Net PIN base 89-91) for crops and livestock taken from FAO. The 1990 value of output was multiplied by the Production Indices of each country to produce a comparable value of output normalized by the production indices of each country. For example, for China we multiply the 1990 value of crop production by the production index at time t.

To estimate the value of output of ruminants and non-ruminants, the procedure is more complicated since there are not readily available production indices for these sectors and the ERS only has an aggregate value of livestock. To overcome these problems we proceeded to estimate production indices for ruminants and non-ruminants using FAO methodology (FAO, 1986), and use these estimates to calculate value shares of ruminant and non-ruminant production.

The production indices for ruminants and non-ruminants are calculated using the Laspeyres formula, where the production quantities (net of seed and feed use) of each commodity are weighted by 1989-91 average international commodity prices and summed for each year. To calculate the index, the aggregate for a given year is divided by the average for the base period 1989-91. This ratio is then multiplied by 100 to obtain the index number. The international prices are calculated using the Geary-Khamis formula and are used to avoid the use of exchange rates for obtaining continental and world aggregates and to facilitate comparison between countries. Table A1 contains the commodities and its international prices used to calculate the production indices:

Some categories of ruminants and non-ruminants were excluded from these calculations because of the lack of price information. The commodities excluded were: Beeswax, Fresh Buffalo Hides, Fresh Cattle Hides, Fur Skins, Goatskins, Fresh Hair of Horses, Offal Nes, Fresh Sheepskins, Skin with Wool Sheep, and Snails Not Sea Snails.

Once the value of output for ruminants and non-ruminants was obtained, we added this up to have a value of livestock production. However, as we compared this value to the value of livestock production reported by ERS, they were not the same. To overcome this problem we calculated value shares in livestock production of ruminants and non-ruminants using the values obtained from the value based production index. We used these shares with the value of livestock from ERS to estimate value of output for ruminants and non-ruminants.

For example, for China, the value of ruminants and non-ruminants were added for each year to calculate a livestock value, and then the value of ruminants (non-ruminants) were divided by this total value to calculate the value share of ruminants in total livestock. This ruminant (non-ruminant) value share was then multiplied by the value of livestock production from ERS to obtain the value of ruminant (non-ruminant) production.

Table A1. Prices of Livestock Products in 1990 International Dollars

Commodities By Group	Price	Commodities By Group	Price
Cow Milk Whole Fresh	286.48	Eggs Excluding Hen	1101.57
Indigenous Cattle Meat	2450.3	Indigenous Chicken Meat	1338.65
Buffalo Milk	319.39	Indigenous Horse Meat	1604.21
Indigenous Buffalo Meat	1055.28	Indigenous Ass Meat	1269.12
In Sheep Milk	359.72	Indigenous Mule Meat	1252.73
Wool, Greasy	3281.47	Camel Milk	293.77
Indigenous Sheep Meat	2281.51	Indigenous Camel Meat	1298.04
Goat Milk	285.5	Rabbit Meat Indigenous	1790.39
Indigenous Goat Meat	1822.23	Indigenous Rodents	887.59
Indigenous Pig meat	1348.78	Indigenous Other Camel	882.58
Hen Eggs	1129.52	Game Meat	1374.02
Indigenous Duck Meat	1587.37	Meat Nes	1014.23
Indigenous Geese Meat	1655.28	Honey	1765.71
Indigenous Other Poultry	1851.34	Cocoons, Reelable	3746.24
Indigenous Turkey Meat	1328.82		

Source: Table 5.3 from Rao, P. "Intercountry Comparisons of Agricultural Output and Productivity" FAO Economic and Social Development Paper No. 112, 1993.

A2. Animal Stock

Given the variability of body sizes of the main animal species across geographical regions, animal units were standardized for comparisons across the world. The weighted average carcass weight of cattle is used as a proxy for animal size. Following Sere and Steinfeld (1996), the OECD member countries value was set to one as reference or base weight, and the factors for other regions computed relative to this value. The animal species used were beef and veil, sheep, goats, pigs, chickens, turkeys, ducks and geese. These species cover most of the animal species used as food around the world. We did not include buffalos, camels, horses or mules because of the small consumption that these species represent.

We transformed all animal units into livestock units (LU) to allow for the calculation of total stocking rates relative the beef cattle in OECD countries. The data used to calculate these conversion factors was collected from FAO, using the year 2000 values. The units for beef cattle, sheep, goats and pigs were carcass weight/yield

(Hectograms/Animal) yields. For chickens, turkey, ducks and geese, these yields are expressed as hectograms per 1,000 animals. Values for duck and geese in the Former Soviet Union were taken from Easter Europe, because they were not available from the FAO database. The resulting conversion factors are in Table A2.

Table A2. Conversion Factors of Animal Stock by Species and Regions

Region	Beef and Veal	Sheep and Goats	Pigs	Chickens	Turkeys	Ducks	Geese
Asia (Former)	0.50	0.05	0.26	4.40	23.38	4.72	14.45
Sub-Saharan Africa	0.46	0.04	0.17	3.33	10.64	6.22	10.62
Eastern Europe	0.63	0.04	0.30	4.81	18.78	7.75	14.95
Latin America & Caribbean	0.74	0.05	0.26	5.25	19.15	7.18	8.55
Near East	0.51	0.06	0.27	4.24	11.12	8.50	13.55
OECD Countries	1.00	0.06	0.30	5.48	27.91	8.44	14.77
USSR (Former)	0.54	0.06	0.27	4.54	21.60	7.75	14.95

Source: FAOSTAT

These values are different from the values used by Nin et al (2003) where for pigs he used a value of 0.2, for sheep and goat 0.1, and for chicken 10, same values used by Hayami and Ruttan (1970). For cattle they used the conversion factors of Sere and Steinfeld in Table A3:

Table A3. Cattle Conversion Factors by Region

Asia	0.42
Sub-Saharan Africa (SSA)	0.46
Eastern Europe and CIS	0.73
Central and South America (CSA)	0.75
West Asia and North Africa (WANA)	0.42
OECD member countries	1.00
Other Developed Countries	0.82

Source: Sere and Steinfeld, 1996

As we compare these values with the values used in this study, we find some differences for Asia, Eastern Europe, and the Near East. Values for Sub-Saharan Africa and Latin America are almost identical.

B3. Animal Feed

Crops and animal feed by year and country was collected from the FAO Commodity Balances (Crops and Livestock and Fish Primary Equivalent). As in Nin et al. (2003) the categories used for feed were: Barley, Bran, other cereals, copra cake, cotton seed, cottonseed cake, fruits excluding wine, groundnut in shell equivalent, groundnut cake, maize, millet, molasses, oats, other oilseed cake, palm cake, palm kernel, pulses, other pulses, rapeseed cake, rapeseed, rice, paddy equivalent, rye, sesame seed, sesame seed cake, sorghum, soybean cake, soybean, roots, sugar beet, sugar cane, sunflower seed, sunflower cake, vegetables, other vegetables, wheat, animal fat, raw animal fat, fish seafood, fish meal, meat, meat meal, milk, offal, edible offal, and whey. In this study we added 4 new categories: Other pulses, other vegetable, raw animal fat and fish meal. These categories were chosen because these are the most used crops and animal products used in animal feed (based of FAO 2000 values of feed consumption).

Feed data was then transformed into a common unit, that is, tons of crude protein consumed by livestock. We used the content of crude protein (%) of each feed to transform feed consumption into tons of protein consumed per country per year. The values for conversion were taken from animal nutrition (Table A4).

Table A4. Crude Protein and Energy Content of Selected Animal Feed

Commodity	Energy (kcal/kg)	Crude Protein (%)	Commodity	Energy (kcal/kg)	Crude Protein (%)
Barley	2.60	0.116	Sesame seed	3.00	0.379
Bran	2.23	0.152	Sesame cake	2.65	0.416
Other cereals	2.63	0.109	Sorghum	2.70	0.109
Copra cake	2.37	0.213	Soy cake	2.78	0.424
Cotton seed	3.13	0.231	Soy	3.00	0.379
Cotton seed cake	2.38	0.414	Roots	0.67	0.022
Fruits	0.60	0.008	Sugar beet	0.55	0.014
Ground nut	2.62	0.376	Sugar cane	0.52	0.015
Ground nut cake	2.76	0.455	Sunflower seed	2.83	0.168
Maize	2.79	0.095	Sunflower cake	1.35	0.196
Millet	2.48	0.121	Vegetables	0.60	0.800
Molasses	2.53	0.062	Other Vegetables	0.60	0.800
Oats	2.45	0.087	Wheat	2.83	0.119
Other cakes	2.76	0.455	Animal fat	8.40	0.000
Palm cake	2.61	0.185	Raw animal fat	8.40	0.000
Palm	2.92	0.274	Fish	2.02	0.569
Pulses	2.69	0.238	Fishmeal	2.02	0.569
Other Pulses	2.69	0.238	Meat	2.54	0.514
Rape cake	2.39	0.370	Meat meal	2.54	0.514
Rape seed	3.20	0.195	Milk	0.58	0.035
Rice	2.71	0.071	Offal	2.54	0.514
Rye	2.58	0.113	Whey	1.40	0.394

Table B. Number of feasible LP Problems in Crops, Ruminants and Non-Ruminants Direction when the Observation being evaluated is from Period t and the Technology is from t + 1 (one LP Problem per year, 1961-2001; max=40)

Country/Region	Crops	Ruminants	Non-ruminants	Country/Region	Crops	Ruminants	Non-ruminants
World	40	40	40	Myanmar	36	21	23
Former USSR	37	40	35	Namibia	13	30	25
Albania	32	40	34	Nepal	14	40	20
Algeria	40	40	37	Netherlands	1	17	7
Angola	40	40	40	New Zealand	2	40	3
Argentina	30	12	8	Nicaragua	26	33	25
Australia	36	20	14	Niger	18	40	23
Austria	40	40	40	Nigeria	38	25	24
Bangladesh	5	15	5	Norway	6	40	14
Belux	2	7	3	Pakistan	0	31	8
Belize	40	22	22	Panama	39	40	39
Benin	20	23	12	Papua New Guinea	36	6	5
Bhutan	5	19	4	Paraguay	40	27	25
Bolivia	40	39	39	Peru	40	39	39
Botswana	32	39	40	Philippines	33	22	26
Brazil	40	40	40	Poland	37	40	30
Bulgaria	13	40	8	Portugal	40	40	39
Burkina	40	40	40	Puerto Rico	0	16	25
Burundi	29	31	27	Romania	34	40	33
Cambodia	40	29	32	Rwanda	9	5	6
Cameroon	32	28	28	Saudi Arabia	18	34	22
Canada	29	13	16	Senegal	40	38	35
Central Africa	24	40	24	Sierra Leone	40	40	40
Chad	37	40	34	Singapore	2	18	27
Chile	36	40	37	Somalia	3	17	13
China	40	40	40	South Africa	37	39	39
Colombia	37	38	21	Spain	40	40	40
Congo Dem	35	19	27	Sri Lanka	38	18	19
Congo Rep	31	15	20	Sudan	40	40	40
Costa Rica	35	33	19	Suriname	40	37	37
Cuba	40	40	40	Swaziland	23	10	8
Czechoslovakia	25	40	23	Sweden	1	22	11
Ivory Coast	39	14	12	Switzerland	7	40	23
Denmark	2	12	6	Syria	9	22	14
Dominican	15	23	10	Tanzania	40	40	40
Ecuador	34	37	28	Thailand	23	21	30
Egypt	2	6	6	Togo	40	33	33
El Salvador	40	40	33	Trinidad & Tobago	18	29	32
Ethiopia dr	27	33	29	Tunisia	40	40	39
Finland	18	40	23	Turkey	40	17	15

Country/Region	Crops	Ruminants	Non-ruminants	Country/Region	Crops	Ruminants	Non-ruminants
France	37	21	10	Uganda	38	31	28
Gabon	28	13	19	UK	36	40	17
Gambia	32	30	27	USA	1	14	5
Germany	39	40	26	Uruguay	1	5	40
Ghana	40	24	30	Venezuela	24	40	37
Greece	40	25	14	Vietnam	38	21	18
Guatemala	40	40	40	Yemen	36	40	39
Guinea	40	40	39	Yugoslavia	32	40	31
Guinea Bissau	40	40	40	Zambia	40	40	40
Guyana	32	11	13	Zimbabwe	40	40	40
Haiti	3	17	7	Asia (Former)	34	34	34
Honduras	38	40	32	Europe (Former)	34	34	34
Hungary	10	19	13	Low Income Countries	40	40	40
Iceland	11	36	27	Africa	40	40	40
India	16	40	13	Africa Developed	18	39	17
Indonesia	40	40	38	Africa Developing	40	40	40
Iran	40	40	40	Africa South of Sahara	40	40	40
Iraq	26	20	23	Asia Developed	13	24	32
Ireland	23	40	27	Asia Developing	40	40	40
Israel	1	12	2	Caribbean	40	40	40
Italy	40	39	35	Developed Countries	40	40	40
Jamaica	27	25	36	Developing Countries	40	40	40
Japan	12	23	22	East & South East Asia	40	40	40
Jordan	35	34	38	Eastern Europe	40	40	40
Kenya	31	40	34	EU 15	40	40	40
Korea Popular	18	12	9	Industrialized Countries	40	40	40
Korea	9	8	3	Latin America & Caribbean	40	40	40
Laos	23	27	26	Least Developed Countries	40	40	40
Lebanon	20	16	11	Low-Income Food Deficit	40	40	40
Lesotho	38	40	39	Near East	40	40	40
Liberia	28	6	15	North & Central America	40	40	40
Libya	19	28	32	North America	6	10	8
Madagascar	40	40	40	Oceania Developed	36	30	9
Malawi	38	40	36	Oceania Developing	40	40	40
Malaysia	23	3	6	Asia and Pacific	40	40	40
Mali	39	40	40	South America	40	40	40
Mauritania	32	40	35	South Asia	11	22	4
Mexico	27	37	40	Transition Markets	40	40	40
Mongolia	18	40	26	Western Europe	40	40	40
Morocco	40	40	40	Asia	40	40	40
Mozambique	40	40	40				
% Countries / Regions feasible	37	48	28				

Appendix Table C1. Production Value Weights used to Aggregate TFP Growth Rates

Region	Share of each sector by region (2001)			
	Crops	Ruminants	Non-Ruminants	Agriculture
Industrialized Countries	22.6	41.2	33.6	28.4
Economies in Transition	8.0	12.1	6.8	8.6
China	23.0	7.7	38.3	22.5
East & South East Asia	8.9	1.5	5.3	6.8
South Asia	14.8	13.4	2.3	12.3
Middle East & North Africa	4.8	4.5	2.1	4.3
Sub Saharan Africa	6.2	5.0	1.7	5.2
Latin America & Caribbean	11.7	14.5	9.8	11.9
Total	100	100	100	100

Region	Share in Agriculture (2001)			
	Crops	Ruminants	Non-Ruminants	Total
World	62	21	18	100
Industrialized Countries	49	30	21	100
Economies in Transition	57	29	14	100
China	63	7	30	100
East & South East Asia	82	5	14	100
South Asia	74	23	3	100
Middle East & N. Africa	69	22	9	100
Sub Saharan Africa	74	20	6	100
Latin America & Caribbean	60	25	15	100

Appendix C2. Comparison of Productivity Growth in Agriculture using 2001 weighted sector averages and directional distance function, and Adjustment Coefficients

Region	Adjustment Coefficient	Period	Weighted			Estimated		
			TFP	EFF	TCH	TFP	EFF	TCH
World		1961-2000	0.94	-0.22	1.17	0.75	-0.34	1.09
		1961-1970	1.11	-0.26	1.38	0.18	-1.94	2.16
		1971-1980	0.11	-0.83	0.95	0.90	0.38	0.51
		1981-1990	1.06	-0.31	1.42	1.15	0.11	1.04
		1991-2000	1.52	0.57	0.95	0.79	0.12	0.66
Industrialized Countries	0.4624	1961-2000	1.19	0.20	0.99	1.36	0.10	1.26
		1961-1970	1.46	0.70	0.75	1.52	0.36	1.15
		1971-1980	1.51	0.52	0.98	1.88	0.57	1.31
		1981-1990	0.74	-0.47	1.23	0.94	-0.65	1.60
		1991-2000	1.05	0.05	1.00	1.10	0.11	0.99
Economies in Transition	0.3704	1961-2000	0.89	-0.29	1.19	0.81	-0.38	1.19
		1961-1970	1.04	-0.17	1.21	0.87	-0.42	1.29
		1971-1980	-0.21	-0.88	0.69	-0.41	-0.98	0.57
		1981-1990	0.70	-0.29	1.01	1.18	0.54	0.64
		1991-2000	2.09	0.21	1.86	1.59	-0.65	2.25
China	0.9847	1961-2000	1.67	-0.47	2.17	1.00	-0.07	1.07
		1961-1970	2.71	-0.20	2.92	2.50	-0.38	2.88
		1971-1980	-1.70	-3.06	1.41	-2.09	-2.73	0.66
		1981-1990	2.71	-0.51	3.39	1.51	0.93	0.57
		1991-2000	3.05	2.01	1.04	2.16	1.96	0.20
East & South East Asia	0.7921	1961-2000	0.18	-0.56	0.75	0.44	-0.55	0.99
		1961-1970	0.48	-0.52	1.01	1.22	-0.38	1.60
		1971-1980	1.07	0.36	0.71	1.29	0.31	0.98
		1981-1990	-0.49	-1.38	0.93	-0.36	-1.60	1.26
		1991-2000	-0.32	-0.68	0.37	-0.38	-0.54	0.16
South Asia	0.695	1961-2000	0.27	-0.21	0.48	0.96	-0.41	1.37
		1961-1970	-0.24	-1.17	0.95	0.99	-0.84	1.85
		1971-1980	-0.55	-0.93	0.39	-0.64	-1.59	0.97
		1981-1990	0.69	0.41	0.29	2.20	-0.30	2.51
		1991-2000	1.19	0.87	0.32	1.31	1.14	0.17
Middle East & North Africa	0.4187	1961-2000	0.03	-0.30	0.34	0.42	-0.69	1.12
		1961-1970	-0.13	-0.57	0.44	0.02	-0.96	1.00
		1971-1980	0.21	-0.18	0.39	1.40	-0.23	1.64
		1981-1990	0.26	-0.02	0.28	0.94	-0.27	1.21
		1991-2000	-0.19	-0.43	0.24	-0.67	-1.30	0.64
Sub Saharan Africa	0.6223	1961-2000	0.21	-0.08	0.29	0.57	-0.10	0.67
		1961-1970	-0.24	-0.71	0.47	0.36	-0.44	0.81
		1971-1980	-0.44	-0.67	0.23	-0.12	-0.26	0.14
		1981-1990	0.75	0.49	0.26	0.73	-0.37	1.10
		1991-2000	0.79	0.59	0.20	1.30	0.68	0.61
Latin America & Caribbean	0.7744	1961-2000	0.77	-0.53	1.30	0.71	-0.50	1.21
		1961-1970	0.05	-1.38	1.46	-0.28	-1.96	1.72
		1971-1980	0.70	-0.70	1.41	0.86	-0.68	1.56
		1981-1990	0.67	-0.11	0.78	0.56	-0.35	0.92
		1991-2000	1.66	0.09	1.57	1.70	1.04	0.66

Table D1. Logistic Function Parameters for Crops Efficiency Levels

Region	Coeff.	Estimate	St. Error	T value	Pr > |t|	R^2	Most recent structural Change
Industrialized Countries	α	-6.3671	1.1442	-5.5646	0.0014	0.85	1993
	β	0.11044	0.0167	6.6154	0.0006		
Economies in Transition	α	-4.55573	1.3452	-3.3868	0.0117	0.62	1992
	β	0.06779	0.0201	3.379	0.0118		
China	α	-4.31135	0.4041	-10.668	<.0001	0.94	1988
	β	0.08171	0.0066	12.3556	<.0001		
East & South East Asia	α	1.32283	0.0613	21.5686	<.0001	0.92	1976
	β	-0.02269	0.0014	-16.1303	<.0001		
Asia Developing	α	-1.24442	0.1196	-10.4027	<.0001	0.83	1982
	β	0.02053	0.0023	8.9738	<.0001		
Middle East & N. Africa	α	-0.83925	0.1422	-5.9031	<.0001	0.52	1982
	β	0.01155	0.0027	4.2478	0.0005		
Sub-Saharan Africa	α	-1.89824	0.1104	-17.191	<.0001	0.94	1985
	β	0.0284	0.0019	14.5778	<.0001		
Latin America & Caribbean	α	0.71592	0.1387	5.1602	0.0001	0.56	1984
	β	-0.01106	0.0025	-4.4008	0.0005		

Table D2. Logistic Function Parameters for Ruminants Efficiency Levels

Region	Coeff.	Estimate	St. Error	T value	Pr > |t|	R^2	Most recent structural Change
Industrialized Countries	α	2.4089	0.1545	15.5871	<.0001	0.76	1981
	β	-0.02303	0.003	-7.5738	<.0001		
Economies in Transition	α	0.89121	0.4332	2.0573	0.0544	0.16	1981
	β	0.01513	0.0085	1.7751	0.0928		
China	α	-7.42567	0.2507	-29.6145	<.0001	0.97	1985
	β	0.11185	0.0044	25.866	<.0001		
East & South East Asia	α	-0.16841	0.0565	-2.9815	0.0063	0.95	1974
	β	-0.02728	0.0014	-19.6788	<.0001		
Asia Developing	α	-2.28252	0.0669	-34.1222	<.0001	0.95	1981
	β	0.02616	0.0013	19.8755	<.0001		
Middle East & N. Africa	α	1.16008	0.0493	23.5084	<.0001	0.96	1974
	β	-0.02822	0.0012	-23.3071	<.0001		
Sub-Saharan Africa	α	-0.71651	0.0456	-15.7023	<.0001	0.47	1976
	β	0.00466	0.001	4.4537	0.0002		
Latin America & Caribbean	α	-1.26845	0.1501	-8.4526	<.0001	0.83	1984
	β	0.02339	0.0027	8.6063	<.0001		

Table D3. Logistic Function Parameters for Non-Ruminants Efficiency Levels

Region	Coeff.	Estimate	St. Error	T value	Pr > |t|	R^2	Most recent structural Change
Industrialized Countries	α	2.07361	0.9747	2.1274	0.0568	0.26	1988
	β	-0.0316	0.0159	-1.9812	0.0731		
Economies in Transition	α	-2.95387	0.7176	-4.1165	0.0034	0.54	1991
	β	0.03264	0.0109	2.9822	0.0175		
China	α	-4.99659	0.6692	-7.4666	0.0001	0.83	1992
	β	0.05719	0.01	5.7299	0.0007		
East & South East Asia	α	-2.16873	0.2003	-10.8273	<.0001	0.82	1993
	β	0.01555	0.0029	5.3219	0.0018		
Asia Developing	α	-2.49062	0.7195	-3.4614	0.0086	0.35	1991
	β	0.02238	0.011	2.0392	0.0758		
Middle East & N. Africa	α	1.48194	0.2035	7.2824	<.0001	0.91	1989
	β	-0.03367	0.0033	-10.3561	<.0001		
Sub-Saharan Africa	α	0.26364	0.5515	0.478	0.6454	0.34	1991
	β	-0.01671	0.0084	-1.9868	0.0822		
Latin America & Caribbean	α	-4.5225	0.5332	-8.4824	<.0001	0.88	1992
	β	0.05376	0.008	6.7606	0.0003		

Table E1. Historical World Productivity Growth Shares by Region by decade (2001 weights)

Regions	Crops			Ruminants			Non-Ruminants		
	TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH
Productivity Growth 1961-70	*1.14*	*-0.12*	*1.26*	*0.00*	*-0.88*	*0.89*	*2.31*	*-0.04*	*2.35*
Industrialized Countries	44	-248	14	-11926	0	24	16	-146	14
Economies in Transition	10	3	9	-2042	3	7	3	122	5
China	45	46	45	-1149	23	25	72	-500	63
East & South East Asia	2	41	6	126	3	2	4	-15	4
South Asia	-2	129	11	7237	26	12	2	-45	1
Middle East & North Africa	-1	22	1	504	4	3	1	-2	1
Sub Saharan Africa	-2	39	2	276	4	3	0	-9	0
Latin America & Caribbean	4	68	10	7075	38	23	1	696	12
Total	100	100	100	100	100	100	100	100	100
Productivity Growth 1971-80	*-0.14*	*-0.82*	*0.68*	*0.31*	*-0.39*	*0.70*	*0.72*	*-1.39*	*2.16*
Industrialized Countries	-280	-16	38	153	-57	36	69	-8	17
Economies in Transition	21	11	9	-7	13	4	4	4	4
China	363	79	20	-50	55	8	-26	101	58
East & South East Asia	-63	-4	8	6	-2	1	11	0	4
South Asia	65	17	7	-17	25	6	0	3	2
Middle East & North Africa	2	2	2	8	1	4	5	-1	1
Sub Saharan Africa	35	7	1	9	0	4	1	-1	0
Latin America & Caribbean	-44	5	15	-1	65	36	36	3	14
Total	100	100	100	100	100	100	100	100	100
Productivity Growth 1981-90	*0.57*	*0.16*	*0.41*	*1.13*	*0.70*	*0.43*	*2.71*	*-3.09*	*6.08*
Industrialized Countries	27	-22	47	25	-5	72	12	19	16
Economies in Transition	12	-10	21	6	5	8	1	4	3
China	38	122	5	49	77	2	76	63	69
East & South East Asia	-11	-48	4	-3	-5	1	2	7	5
South Asia	10	22	5	16	26	1	3	2	2
Middle East & North Africa	3	5	2	0	-3	4	0	0	0
Sub Saharan Africa	10	30	2	1	-1	5	0	0	0
Latin America & Caribbean	11	1	14	6	6	7	6	4	5
Total	100	100	100	100	100	100	100	100	100
Productivity Growth 1991-00	*1.33*	*0.68*	*0.65*	*1.06*	*0.50*	*0.57*	*2.72*	*0.27*	*2.43*
Industrialized Countries	21	11	32	19	-23	57	17	-17	21
Economies in Transition	16	5	28	5	-9	18	7	15	6
China	36	70	2	45	96	0	60	128	52
East & South East Asia	-3	-7	0	0	-1	1	1	-36	5
Middle East & North Africa	12	21	2	18	18	18	2	0	2
South Asia	-1	-2	1	-2	-8	4	0	-8	1
Sub Saharan Africa	4	6	2	3	7	0	0	-7	1
Latin America & Caribbean	14	-5	34	10	19	2	12	25	11
Total	100	100	100	100	100	100	100	100	100

Table E2. Projected World Productivity Growth Shares by Region by decade (2001 weights)

Regions	Crops			Ruminants			Non-Ruminants		
	TFP	EFF	TCH	TFP	EFF	TCH	TFP	EFF	TCH
Productivity Growth 2001-10	*1.30*	*0.56*	*0.74*	*1.13*	*0.48*	*0.65*	*4.64*	*1.52*	*3.05*
Industrialized Countries	26	23	28	13	-26	42	6	-17	18
Economies in Transition	13	13	13	6	2	9	4	3	4
China	39	58	25	40	79	11	73	95	61
East & South East Asia	-4	-15	5	-2	-6	2	4	3	5
South Asia	12	18	8	20	33	10	2	2	2
Middle East & North Africa	2	2	1	-1	-7	4	0	-1	1
Sub Saharan Africa	5	10	2	3	2	3	0	-1	0
Latin America & Caribbean	6	-9	17	21	23	20	12	17	9
Total	100	100	100	100	100	100	100	100	100
Productivity Growth 2011-20	*0.97*	*0.25*	*0.71*	*0.87*	*0.22*	*0.65*	*3.81*	*1.11*	*2.66*
Industrialized Countries	27	18	29	14	-67	42	6	-27	20
Economies in Transition	12	18	10	7	4	9	4	4	4
China	36	63	26	29	79	11	71	103	57
East & South East Asia	-6	-36	5	-2	-13	2	5	4	6
South Asia	15	35	8	24	65	10	2	2	2
Middle East & North Africa	2	5	1	-1	-16	4	0	-2	1
Sub Saharan Africa	6	18	2	3	4	3	0	-1	0
Latin America & Caribbean	8	-21	18	26	44	20	12	18	10
Total	100	100	100	100	100	100	100	100	100
Productivity Growth 2021-30	*0.79*	*0.09*	*0.70*	*0.70*	*0.05*	*0.65*	*3.16*	*0.70*	*2.43*
Industrialized Countries	29	18	30	14	-320	42	6	-48	22
Economies in Transition	11	29	8	9	13	9	4	5	4
China	33	84	26	20	124	11	69	118	54
East & South East Asia	-8	-112	5	-3	-54	2	6	6	6
South Asia	17	90	8	27	238	10	2	3	2
Middle East & North Africa	3	12	1	-2	-73	4	0	-4	1
Sub Saharan Africa	7	44	2	4	16	3	0	-2	1
Latin America & Caribbean	9	-64	18	30	155	20	13	20	11
Total	100	100	100	100	100	100	100	100	100
Productivity Growth 2031-40	*0.70*	*0.00*	*0.70*	*0.60*	*-0.05*	*0.65*	*2.79*	*0.34*	*2.43*
Industrialized Countries	31	-189	30	13	410	42	6	-106	22
Economies in Transition	11	-501	8	11	-13	9	4	9	4
China	31	-1217	26	16	-48	11	68	163	54
East & South East Asia	-10	3889	5	-3	62	2	7	12	6
Middle East & North Africa	18	-2508	8	29	-233	10	3	6	2
South Asia	3	-366	1	-3	87	4	0	-7	1
Sub Saharan Africa	7	-1146	2	5	-18	3	0	-4	1
Latin America & Caribbean	10	2138	18	33	-147	20	13	28	11
Total	100	100	100	100	100	100	100	100	100

Table F1. Historical Productivity Growth Composition by decade and region

Country/Region	Crops			Ruminants			Non-Ruminants			Share of each sector in Agriculture			
	EFF	TCH		EFF	TCH		EFF	TCH		Crops	Ruminants	Non Ruminants	Total
Productivity Growth 1961-00	*-0.03*	*0.75*		*-0.03*	*0.65*		*-1.08*	*3.23*		*0.72*	*0.62*	*2.10*	*0.94*
World	-5	105	100	-5	105	100	-50	150	100	47	14	40	100
Industrialized Countries	36	64	100	7	93	100	-29	129	100	60	18	22	100
Transition Markets	-21	121	100	-66	166	100	-55	155	100	72	9	19	100
China	-8	108	100	66	34	100	-55	155	100	28	12	60	100
East and South East Asia	-1423	1523	100	419	-319	100	-116	216	100	11	-6	95	100
South Asia	-124	224	100	-35	135	100	-40	140	100	48	29	23	100
Near East	963	-863	100	3978	-3878	100	-34	134	100	-53	-13	166	100
Sub-Saharan Africa	-50	150	100	-8	108	100	-50	150	100	52	35	14	100
Latin America & Caribbean	-44	144	100	-885	985	100	-43	143	100	59	3	38	100
Productivity Growth 1961-70	*-0.12*	*1.26*		*-0.88*	*0.89*		*-0.04*	*2.35*		*1.14*	*0.00*	*2.31*	*1.11*
World	-11	111	100	-6049	6149	100	-2	102	100	63	0	37	100
Industrialized Countries	63	37	100	2	98	100	14	86	100	73	11	16	100
Transition Markets	-3	103	100	-65	165	100	-57	157	100	77	9	15	100
China	-11	111	100	-751	851	100	11	89	100	51	1	48	100
East and South East Asia	-205	305	100	1288	-1188	100	5	95	100	45	-1	56	100
South Asia	983	-883	100	182	-82	100	32	68	100	39	92	-31	100
Near East	264	-164	100	418	-318	100	4	96	100	116	33	-49	100
Sub-Saharan Africa	232	-132	100	749	-649	100	31	69	100	107	8	-15	100
Latin America & Caribbean	-184	284	100	273	-173	100	-660	760	100	453	-435	82	100
Productivity Growth 1971-80	*-0.82*	*0.68*		*-0.39*	*0.70*		*-1.39*	*2.16*		*-0.14*	*0.31*	*0.72*	*0.11*
World	595	-495	100	-122	222	100	-180	280	100	-83	61	121	100
Industrialized Countries	34	66	100	47	53	100	24	76	100	57	23	20	100
Transition Markets	319	-219	100	241	-141	100	-179	279	100	104	26	-29	100
China	126	-26	100	138	-38	100	972	-872	100	83	8	9	100
East and South East Asia	41	59	100	55	45	100	0	100	100	75	5	20	100
South Asia	156	-56	100	185	-85	100	-2692	2792	100	84	16	0	100
Near East	463	-363	100	-13	113	100	40	60	100	-23	58	65	100
Sub-Saharan Africa	120	-20	100	6	94	100	78	22	100	135	-27	-8	100
Latin America & Caribbean	-63	163	100	-11803	11903	100	-13	113	100	46	-1	55	100

Table F1. Historical Productivity Growth Composition by decade and region (*continued*)

Country/Region	Crops			Ruminants			Non-Ruminants			Share of each sector in Agriculture			
	EFF	TCH		EFF	TCH		EFF	TCH		Crops	Ruminants	Non Ruminants	Total
Productivity Growth 1981-90	*0.16*	*0.41*		*0.70*	*0.43*		*-3.09*	*6.08*		*0.57*	*1.13*	*2.71*	*1.06*
World	28	72	100	62	38	100	-103	203	100	33	22	45	100
Industrialized Countries	-22	122	100	-12	112	100	-168	268	100	46	27	27	100
Transition Markets	-23	123	100	49	51	100	-323	423	100	69	22	9	100
China	90	10	100	98	2	100	-86	186	100	22	19	60	100
East and South East Asia	127	-27	100	116	-16	100	-322	422	100	111	18	-29	100
South Asia	61	39	100	99	1	100	-65	165	100	41	45	14	100
Near East	49	51	100	1449	-1349	100	-133	233	100	90	-3	13	100
Sub-Saharan Africa	86	14	100	-59	159	100	-93	193	100	88	7	5	100
Latin America & Caribbean	3	97	100	55	45	100	-75	175	100	46	19	36	100
Productivity Growth 1991-00	*0.68*	*0.65*		*0.50*	*0.57*		*0.27*	*2.43*		*1.33*	*1.06*	*2.72*	*1.52*
World	51	49	100	47	53	100	10	90	100	54	14	32	100
Industrialized Countries	26	74	100	-54	154	100	-10	110	100	58	14	28	100
Transition Markets	15	85	100	-80	180	100	20	80	100	74	6	19	100
China	97	3	100	100	0	100	21	79	100	43	15	42	100
East and South East Asia	103	-3	100	-754	854	100	-315	415	100	124	-1	-23	100
South Asia	91	9	100	48	52	100	2	98	100	66	27	6	100
Near East	158	-58	100	216	-116	100	1863	-1763	100	52	45	3	100
Sub-Saharan Africa	81	19	100	96	4	100	-874	974	100	81	18	1	100
Latin America & Caribbean	-18	118	100	88	12	100	20	80	100	59	11	30	100

Table F2. Projected Productivity Growth Composition by decade and region

Country/Region	Crops			Ruminants			Non-Ruminants			Share of each sector in Agriculture			
	EFF	TCH		EFF	TCH		EFF	TCH		Crops	Ruminants	Non Ruminants	Total
Productivity Growth 2001-40	*0.22*	*0.71*		*0.17*	*0.65*		*0.92*	*2.64*		*0.94*	*0.82*	*3.60*	*1.38*
World	24	76	100	21	79	100	26	74	100	42	12	46	100
Industrialized Countries	19	81	100	-139	239	100	-141	241	100	72	11	17	100
Transition Markets	35	65	100	12	88	100	30	70	100	64	12	24	100
China	45	55	100	68	32	100	40	60	100	29	7	64	100
East and South East Asia	162	-62	100	156	-56	100	23	77	100	651	69	-620	100
South Asia	59	41	100	68	32	100	28	72	100	61	29	10	100
Near East	52	48	100	272	-172	100	441	-341	100	143	-32	-11	100
Sub-Saharan Africa	75	25	100	30	70	100	1854	-1754	100	86	15	0	100
Latin America & Caribbean	-75	175	100	41	59	100	39	61	100	26	27	47	100
Productivity Growth 2001-10	*0.56*	*0.74*		*0.48*	*0.65*		*1.52*	*3.05*		*1.30*	*1.13*	*4.64*	*1.86*
World	43	57	100	42	58	100	33	67	100	43	13	44	100
Industrialized Countries	38	62	100	-85	185	100	-96	196	100	73	11	16	100
Transition Markets	43	57	100	14	86	100	30	70	100	70	9	21	100
China	64	36	100	84	16	100	43	57	100	31	9	59	100
East and South East Asia	180	-80	100	161	-61	100	24	76	100	-743	-94	937	100
South Asia	63	37	100	72	28	100	29	71	100	61	29	10	100
Near East	54	46	100	361	-261	100	711	-611	100	123	-17	-5	100
Sub-Saharan Africa	79	21	100	31	69	100	-24086	24186	100	87	13	0	100
Latin America & Caribbean	-66	166	100	47	53	100	48	52	100	25	26	50	100
Productivity Growth 2011-20	*0.25*	*0.71*		*0.22*	*0.65*		*1.11*	*2.66*		*0.97*	*0.87*	*3.81*	*1.45*
World	26	74	100	25	75	100	29	71	100	41	12	47	100
Industrialized Countries	18	82	100	-116	216	100	-126	226	100	70	12	18	100
Transition Markets	39	61	100	12	88	100	31	69	100	64	12	23	100
China	47	53	100	70	30	100	43	57	100	29	7	64	100
East and South East Asia	167	-67	100	157	-57	100	23	77	100	1631	182	-1713	100
South Asia	61	39	100	69	31	100	29	71	100	61	29	10	100
Near East	53	47	100	290	-190	100	483	-383	100	136	-27	-9	100
Sub-Saharan Africa	77	23	100	30	70	100	2663	-2563	100	86	14	0	100
Latin America & Caribbean	-72	172	100	43	57	100	42	58	100	26	26	48	100

Table F2. Projected Productivity Growth Composition by decade and region (*continued*)

Country/Region	Crops			Ruminants			Non-Ruminants			Share of each sector in Agriculture			
	EFF	TCH		EFF	TCH		EFF	TCH		Crops	Ruminants	Non Ruminants	Total
Productivity Growth 2021-30	*0.09*	*0.70*		*0.05*	*0.65*		*0.70*	*2.43*		*0.79*	*0.70*	*3.16*	*1.19*
World	11	89	100	8	92	100	22	78	100	41	12	47	100
Industrialized Countries	7	93	100	-164	264	100	-163	263	100	71	11	18	100
Transition Markets	30	70	100	11	89	100	30	70	100	59	15	26	100
China	29	71	100	47	53	100	39	61	100	28	5	67	100
East and South East Asia	158	-58	100	155	-55	100	23	77	100	426	43	-369	100
South Asia	58	42	100	67	33	100	28	72	100	61	29	10	100
Near East	51	49	100	253	-153	100	393	-293	100	152	-38	-14	100
Sub-Saharan Africa	73	27	100	30	70	100	1373	-1273	100	85	16	-1	100
Latin America & Caribbean	-78	178	100	39	61	100	35	65	100	27	27	45	100
Productivity Growth 2031-40	*0.00*	*0.70*		*-0.05*	*0.65*		*0.34*	*2.43*		*0.70*	*0.60*	*2.79*	*1.05*
World	0	100	100	-8	108	100	12	88	100	41	12	47	100
Industrialized Countries	2	98	100	-244	344	100	-208	308	100	75	9	16	100
Transition Markets	19	81	100	10	90	100	27	73	100	57	16	27	100
China	15	85	100	24	76	100	30	70	100	27	4	69	100
East and South East Asia	151	-51	100	153	-53	100	22	78	100	298	27	-225	100
South Asia	54	46	100	64	36	100	26	74	100	61	28	10	100
Near East	49	51	100	231	-131	100	347	-247	100	171	-52	-19	100
Sub-Saharan Africa	69	31	100	30	70	100	973	-873	100	83	17	-1	100
Latin America & Caribbean	-85	185	100	36	64	100	27	73	100	29	28	44	100